

AN
INTRODUCTION
TO
NATURAL PHILOSOPHY.

ILLUSTRATED WITH COPPER PLATES.

By *WILLIAM NICHOLSON.*

Non enim me cu quam mancipavi, nullius nomen fero multum magnorum virorum iudicio credo, aliquid et meo vindico. Nam illi quoque, non inventa, sed quærenda, nobis reliquerunt
SENECA.

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AN
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TO
NATURAL PHILOSOPHY.



B O O K II.

S E C T. III.

Of Fluids.

C H A P. I.

OF HYDROSTATICS, OR THE EFFECTS WHICH ARISE
FROM THE GRAVITY OF FLUIDS.

A FLUID is a body whose parts readily yield to a
any impression, and in yielding, are easily moved
amongst each other.

The cause of fluidity is not perfectly known. Some are of opinion that the particles of fluids are spherical, and, in consequence of their touching each other in few points, cohere very slightly, and easily slip or slide over each other. But that the particles of fluids are of the same nature or figure

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as

as those of solids, seems probable, from the very frequent conversion of the one into the other. It does not seem rational to suppose that the particles of gold, lead, glass, &c. when in fusion, are rendered spherical by the action of the fire, and when that action ceases, that the particles resume their former figure, as the bodies become solid by cooling. Neither can we easily imagine, that the particles of water are changed by cold, when it becomes a solid and brittle lump of ice, and are again reinstated in their original form, when the ice, by dissolution, is again turned to water.

- c The original cause of fluidity, then, does not appear to consist in the figure of the particles, but simply in their want of cohesion.
- D If the particles of a body cohere strongly together, it is evident that they will not easily move amongst each other. An imperfect cohesion must therefore be one of the properties of a fluid mass; and that the smallness of the particles is requisite to fluidity, will appear by considering, that the surface of a body composed of small particles must be much more smooth and even than the surface of a body composed of larger particles: that two flat bodies may be conceived to consist of particles so small that their surfaces shall differ insensibly from perfect planes: that these bodies, if placed on each other, will slide without the least sensible friction: and that if the particles of these bodies thus placed on each other be, by any means, deprived of the whole, or the greatest part of their cohesion, the
bodies

bodies will not only slide on each other in the just mentioned plane, but the parts of the mass will also slide on each other in any other direction whatsoever. Consequently they will readily yield to any impression, and in yielding, be easily moved amongst each other; that is, they will constitute a fluid mass.

But the enquiry, wherein consists that change E which bodies undergo when their consistency is altered so as to make them assume a fluid form, either dense and almost incompressible, or vaporous and elastic, belongs not to this place, but to chemistry.

That science, which treats of the effects arising F from the weight of fluids, is called hydrostatics.

The parts of fluids are heavy; but because the G upper parts rest upon, and are sustained by, the parts beneath, and because, by the property of fluids, the parts are readily moved in all directions, upwards as well as downwards, they do not at first consideration appear to be heavy.

The bottom of an upright prismical or cylindrical vessel is pressed by the whole weight of the fluid contained; and as the weight of the fluid is in proportion to its height, so is likewise the pressure. Thus, in the cylinder *AB* (fig. 114) when filled to *c*, the bottom is pressed by, or sustains a certain weight, suppose one pound; if it be filled to *D*, the pressure becomes two pounds; if to *A*, three pounds, &c. the heights between *B*, *c*, *D*, and *A* being supposed equal. H

The whole of any fluid mass may be imagined to I consist of a number of columns of an inconsiderable

thickness, which stand perpendicularly on the base of the containing vessel, and press the same with their respective weights. The pressure, then, if the height remain the same, is as the number of columns, and this number is as the area of the
 K base. Consequently in vessels whose bases differ as to area, and which contain fluids of the same density, but different heights, the pressure will be in the compound ratio of the bases and heights; that is, in numbers, as the area of the base multiplied by the height of the fluid in one vessel, is to the area of the base multiplied by the height of the fluid in the other vessel, so is the pressure sustained by the base of the one to the pressure sustained by the base of the other vessel.

L In like situations, the pressures of fluids will be as their densities.

M The densities being discoverable most readily by the different weights of bodies of the same bulk, the comparative densities of bodies are therefore called their specific gravities.

N If the columns of which a fluid mass was supposed to consist (3, 1) were formed of particles lying in perpendicular right lines, the pressure of the fluid would be exerted on the bottom of the vessel only; but, as they are situated in every irregular position, there must, of consequence, be a pressure exerted in every direction; which pressure must be equal at equal depths. For if any part of the whole mass were not equally pressed on all sides, it would move towards the side on
 which

which the pressure was least; and would not become quiescent till such equal pressure was obtained. The quiescence of the parts of fluids is therefore a proof that they are equally pressed on all sides.

On this account it is, that fluids, as far as they are not prevented by external accidents, always conform their upper surface to the plane of the horizon. For if any column or part of the fluid be elevated above the rest, it will descend partly by sinking into the fluid, and partly by its lateral pressure, that will cause it to spread sideways over the surface, till it becomes uniformly of the same height, or horizontal.

The equal pressure of fluids in every direction, P being understood, may be applied to account for many phenomena that happen to them in different circumstances; some of which are the following.

The horizontal bottom of a vessel is pressed by, Q and sustains no more nor less than the weight of a column of the fluid it contains, whose base is the bottom itself, and whose height is that of the fluid.

In the vessel $E C D F$ (fig. 115) the bottom $C D$ R sustains no more than the column $A B D C$. For the other parts of the contained fluid can only press the column $A B D C$ laterally, and therefore contribute not at all to the increase of the weight or pressure on the bottom $C D$; but rest intirely on the sides $E C$ and $F D$.

Also in the vessel $E C D F$ (fig. 116), the bottom $E F$ sustains a pressure equal to the weight of a column whose base is $E F$, and height equal to $C A$.

For the pressure at AB is equal to the weight of the column $ABDC$, and its lateral pressure, which is equal to the same weight, must cause the parts between EA and BF to press the bottom with an equal force in proportion to the surfaces they cover. Consequently, the effect will be the same as if the whole fluid were of the height CA .

T From these two cases combined, the reason is evident, why fluids contained in the several parts of vessels (fig. 117), remain every where at the same height. For the lowest part where they communicate, may be regarded as the common base; and the fluids, which rest thereon, are in equilibrio then only, when their heights are equal, however their quantities may vary.

U The hydrostatical paradox, as by some it is called, depends on the equal pressure of the parts of fluids every where at the same depth. It is this.

V Any quantity of fluid, however small, may be made to counterpoise and sustain any weight, how large soever.

W Let $ADBG$ (fig. 118) represent a cylindrical vessel, to the inside of which is fitted the cover c , which, by means of leather at the edge, will easily slide up and down in the internal cavity, without permitting any water to pass between it and the surface of the cylinder. In the cover is inserted the small tube CF , open at top, and communicating with the inside of the cylinder beneath the cover at c . The cylinder is filled with water, and the cover put on. Then, if the cover be loaded with

with the weight, suppose of a pound, it will be depressed, the water will rise in the tube to e , and the weight will be sustained. If another pound be added, the water will rise through an equal space to f , and the weight will be sustained, and so forth, according to the weight added, and the length of the tube. Now, the weight of the water in the tube is but a few grains; yet its lateral pressure serves to sustain as much as the weight of a column of water, whose base is equal to that of the cylinder, and height equal to that in the tube. Thus, the column ec produces a pressure in the water contained in the cylinder, equal to what would have been produced by the column $Aadd$; and, as this pressure is exerted every way equally, the cover will be pressed upwards with a force equal to the weight of $Aadd$: consequently, if $Aadd$ would weigh a pound, ec will sustain a pound: and the like is true of other heights and weights. And by diminishing the diameter of the tube, any quantity of water, how small soever, will, in theory, sustain any weight, however large.

The same may be shewn more simply thus: x

Let $AGBD$ (fig. 119) represent a hollow cylinder, and MN a cylinder of wood, which nearly fills its cavity. In the cylinder, suppose a little water, whose surface is gb ; then, if the wooden cylinder be put into the hollow one, the water will rise between the surfaces to a and d , and the wood will be sustained floating. The nearer the wooden cylinder approaches to the size of the cavity, the less water is necessary for the experiment.

C H A P. II.

CONCERNING BODIES IMMERSED IN FLUIDS, AND
THE METHODS OF FINDING SPECIFIC GRAVITIES.

y IF a solid body be plunged in a fluid, it will be pressed on all sides, but not equally. Let DBEC (fig. 120) represent a solid prismatic body, immersed, with its axis vertical, in the fluid contained in the vessel FGIH, then the sides DC and BE will be equally pressed; the upper surface DB will be pressed with the weight of a column, whose base is DB, and height AD, and the under surface will be pressed upwards with a force equal to the weight of a column whose height is AC (4, N). The body will therefore be impelled upwards by a force equal to the excess of AC above AD; that is, equivalent to the weight of a column of the fluid whose length is DC, the base being all along supposed to

z be unvaried. Whence it appears, that every prism, whose axis is perpendicular to the horizon, will, if it be totally immersed in any fluid, be impelled upwards by a force, which is equal to the weight of a quantity of the fluid of the same bulk with the prism. And since any solid whatsoever may be conceived to be formed of an indefinite number of such prisms, it is evident that the rule is true of all bodies, without respect to figure.

But

But as all bodies, by the force of gravity, tend downwards, it depends upon the absolute weight of the immersed body, whether it shall ascend or descend. If the weight of the body exceed that of an equal bulk of the fluid, the excess of force tends downwards, and it will descend; but, on the contrary, if the weight of the body be less than that of an equal bulk of the fluid, the above-mentioned pressure will prevail, and it will ascend; if both be precisely equal, the body will remain at rest any where in the fluid.

These things being considered, it appears that any body, how heavy soever, may be made to swim, or any body, how light soever, to sink, if means be used to keep off the pressure of the fluid from the one or other side, as circumstances require: for if ADE be supposed to represent an open tube, the head of a column of the fluid, and the body $BCDE$ be applied closely to its lower orifice, so that the fluid may not enter the tube, the pressure on DB will be taken off, and consequently the body will be pressed upwards with a force equal to the whole column AC . If that column be of sufficient length, that is, if the body be immersed sufficiently deep, the pressure will exceed the gravity of the body, and therefore sustain it. In the same manner, if M be a body applied to the open end of a tube, which is closed at N , the inferior pressure being taken off, the body will not rise, however light, but remain immersed, by means of the pressure on the superior surface.

When

P When a body floats at the surface of a fluid, the quantity of the fluid, displaced by the part immersed, is equal in weight to the floating body. For since the body presses downwards with its whole weight, it must sink till the pressure, which the fluid exerts upwards, is equal to that weight. In this situation, suppose the fluid to be congealed, and the solid then removed: a cavity will be left in the fluid corresponding in form and magnitude with the immersed part of the solid. Imagine this cavity be filled with a quantity of the same fluid, so that its surface may be level with the rest, and the whole fluid then thawed. The fluid which occupies the place of the solid will then be pressed upwards with a force equal to that sustained before by the solid, namely, equal to the weight of the solid. But it is not moved by that force, for the surface must continue level (5, o), as before the thaw. The last mentioned quantity of fluid must therefore press downwards with an equal force. That is to say, the weight of a quantity of fluid equal in bulk to the immersed part of a solid which floats on its surface, is equal to the whole weight of the solid.

Q By the same argument, it follows, that if a floating body be loaded with weights, so as to cause it to sink deeper in the fluid, the additional parts immersed will in bulk be equal to, or displace, parts of the fluid, whose weights are equal to those the floating body was loaded with.

Since

Since bodies of equal bulks will lose the same quantity of absolute weight when immersed in fluids of equal density, it follows obviously, that the bulks of bodies are in proportion to the loss of weight they sustain by immersion in a given fluid. Whence we have an exact method of determining the bulks of bodies whose weights are known, and from thence finding their specific gravities. For,

As the bulk of one body, or the weight it loses by immersion,

Is to its mass of matter, or absolute weight,

So is the bulk of any other body, or the weight it loses by immersion,

To the mass of matter, or absolute weight, it would have had if of the same specific gravity with the first body. Which weight last found being compared with the real weight of the latter body, shews the proportion of their specific gravities.

For example: if 34 oz. of lead be weighed in water, and the diminution be 3 oz. and 15 oz. of tin be also weighed in water, and the diminution appear 2 oz. it is required to determine the proportion of their specific gravities. For which purpose,

As the diminution in the lead 3, is to its weight 34, so is the diminution in the tin 2, to the weight of a mass of lead of the same bulk $22\frac{2}{3}$ oz. which is to 15 as the specific gravity of lead is to that of tin, that is to say, in lower terms, nearly as $11\frac{1}{3}$ to $7\frac{1}{2}$.

But

E But it is more usual and convenient to make rain-water the standard, and refer the other substances to it: thus, in the instances just mentioned, the weight of a mass of water equal in bulk to the lead is 3 oz.: lead is therefore to water as 34 to 3, or as $11\frac{1}{3}$ to 1; and in like manner, tin is to water as 15 to 2, or as $7\frac{1}{2}$ to 1.

M When the solid is lighter than the fluid in which it is weighed, an additional body of greater density may be joined to it: for instance, suppose a piece of cedar-wood, weighing 92 dwts. were required to be weighed; join to it, by means of a small hair or thread, a piece of lead, whose weight in water is known, and weigh them immersed together. The lead will then appear to weigh less by 58 dwts. than it did without the addition of the cedar; from whence it is evident that the cedar is impelled upwards by a force that exceeds its own weight by that quantity, or, in other words, that a quantity of water equal in bulk to the cedar, will weigh $92 + 58$, or 150 dwts.; consequently the specific gravities of water and cedar are in proportion as 150 to 92, or in lower terms, as 1 to $\frac{6}{5}$ nearly.

N In this experiment it is necessary first to smear the wood lightly with some fat substance, otherwise the water will be imbibed by the wood, and will render it specifically heavier than before. In fact, wood is not specifically lighter than water, but by means of the air-vessels which run through its substance.

The

The best method to discover the specific gravities of fluids is, to weigh the same substance in different fluids; and because the diminution it suffers in weight is equal to the weight of a quantity of the fluid of the same bulk, we thence obtain the weights of equal quantities of different fluids, and the specific gravities are as those weights; thus, if a piece of glass weighed in the concentrated acid called oil of vitriol, lose 85 grs. and when weighed in water only 40 grs. their specific gravities will be as those numbers, or in lower terms, as $21\frac{1}{4}$ to 10.

The hydrometer, or instrument usually applied to find the specific gravities of liquids, is constructed as follows: AB (fig. 121) is a tube of glass, joined to a hollow ball c, at the bottom of which is a smaller ball d. In the cavity d is placed a quantity of quicksilver, by which the instrument is so poised, that it swims in proof spirits of wine immersed to the point m. A quantity of proof spirits equal in weight to the whole instrument, will therefore be equal in bulk to the immersed part (10, F). If it be immersed in another liquid, whose specific gravity is greater, it will swim with the tube higher out of the water, suppose to the point n. Then the weights of the quantities displaced remaining the same, their bulks will be as the immersed parts of the hydrometer, and the specific gravities of the fluids will be inversely as those bulks. The proportion which any length of the tube bears to the

the

the whole bulk of the instrument being known, it will not be difficult to graduate the tube so as to indicate the specific gravities by inspection. But this, however, is scarcely ever done.

- Q This instrument is very confined in its use. For if the liquors differ considerably in specific gravity, they exceed the limits of the graduation: thus the hydrometer, adapted for spirits, will swim in water with part of the ball above the surface; and if it be adapted to water, it will not swim in spirits at all. It is true, this may be remedied, either by lengthening or widening the tube: but the first is inconvenient, and the latter would make the graduations so short, as to render them of little use.
- R To make this instrument of more service, there has been added a little plate or dish *DD* (fig. 122) at the top of the tube, upon which may be placed weights, as convenience requires. For example, if the whole instrument float immersed in spirits to the point *M*, it will require an additional weight to sink it to the same depth in water. Suppose the instrument to weigh 10 dwts, and to be adjusted to rectified spirits of wine, it will then require the addition $1\frac{5}{8}$ dwt. to sink it to the same point in water. Consequently it appears, that the specific gravity of water is to that of spirits of wine as $11\frac{5}{8}$ to 10, or in lower terms, as 1 to $\frac{86}{100}$.
- S This is the best hydrometer, both in respect to exactness and facility in practice. The instrument used by the officers of Excise, is very well adapted

for its purpose, which is more confined: it differs from that here described, by having its additional weights screwed on at a stem at *z*. These instruments are usually of copper.

An attempt has been made * to adapt the hydrometer to the general purpose of finding the specific gravity, both of solids and fluids (fig. 123.) *A* is a hollow ball of copper; *B* is a dish affixed to the ball by a short slender stem *D*; *C* is another dish affixed to the opposite side of the ball by a kind of stirrup. In the instrument actually made, the stem *D* is of hardened steel, $\frac{1}{8}$ of an inch in diameter, and the dish *C* is so heavy as in all cases to keep the stem vertical, when the instrument is made to float in any liquid. The parts are so adjusted that the addition of 1000 grains, in the upper dish *B*, will just sink it in distilled water, at the temperature of 60° of Fahrenheit's thermometer, so that the surface shall intersect the middle of the stem *D*. Let it now be required to find the specific gravity of any fluid. Immerse the instrument therein, and by placing weights in the dish *B* cause it to float, so that the middle of its stem *D* shall be cut by the surface of the fluid. Then, as the known weight of the instrument added to 1000 grains; is to the same known weight added to the weights used in producing the last equilibrium: so is the weight of a quantity of distilled water displaced by the floating instrument; to the weight of an equal bulk of the fluid under

* By the author of this work.

consideration. And these weights give the ratio of the specific gravities (4, M). Again, let it be required to find the specific gravity of a solid body less than 1000 grains. Place the instrument in distilled water, and put the body in the dish B. Make the adjustment of sinking the instrument to the middle of the stem, by adding weights in the same dish. Take those weights from 1000 grains, and the remainder will be the weight of the body. Place now the body in the lower dish c, and add more weight in the upper dish B, till the adjustment is again obtained. The weight last added will be the loss the solid sustains (8. z, A) by immersion, and is the weight of an equal bulk of water. Consequently the specific gravity of the solid compared with water, is as its weight to the loss it sustains by immersion.

v This instrument was found to be sufficiently accurate to give weights true to less than one twentieth of a grain.

v Experiments concerning specific gravities are more difficult to be made with accuracy than authors in general seem to imagine. For we often see tables of specific gravities carried to four, five, and even six places of figures; whereas a difference of a few degrees in the temperature of the water will change the fourth figure. In different specimens of the same wood, the specific gravities will vary in the third figure, as will also metals cast out of the same melting, but cooled more quickly or slowly; and these also are alterable by hammering

ing*. Natural and artificial compounds have likewise great varieties of density in the several specimens denoted by the same name.

A Table of Specific Gravities, extracted from various Authors.

Names	Authors.	Sp. Gravity.
Platina - - -	Kirwan - - -	23.000
Gold - - -	Muschenbroek 19.238 to 19.640	
Gold standard of George II.	Muschenbroek -	17.150
Silver - - -	Kirwan, Muschen, -	11.091
Copper - - -	Kirwan -	8.7 to 9.300
Steel soft - - -	Muschenb. -	7.738 to 7.8955
Steel elastic - - -	Muschenbroek -	7.809
Iron bar - - -	Muschenbroek -	7.60 to 7.875
Lead - - -	Muschenbroek 11.226 to 11.479	
Tin - - -	Muschenbroek 7.000 to 7.450	
Mercury - - -	Muschenbroek 13.55 to 14.110	
Zink - - -	Kirwan - - -	6.9 to 7.24
Regulus of antimony -	Kirwan - - -	6.860
Regulus of arsenic - -	Kirwan - - -	8.310
Bismuth - - -	Kirwan - - -	9.6 to 9.7
Cobalt, the regulus -	Kirwan - - -	7.7
Nickel - - -	Kirwan - - -	7.421 to 9.000
Regulus of manganese -	Kirwan - - -	6.850
Wolfram, the regulus -†	De Luyart - - -	17.6
Common brimstone -	Muschenbroek - - -	1.8
Fine glass - - -	Muschenbroek 3.150 to 3.380	
Plate glass - - -	Muschenbroek - - -	2.938
Plate glass - - -	B. Martin - - -	2.75
Green glass for retorts, &c.	Muschenbroek - - -	2.620

* Experiments frequently repeated by the Author have shewn the specific gravity of two nearly equal smooth cylinders of lead, cast out of the same fusion were to each other as 1138 to 1125.

† A chemical analysis of wolfram. London, 1785.

Names.		Authors.		Sp. Gravity.
Crown glass	-	B. Martin	-	2.52
White flint	-	B. Martin	-	3.29
White flint	-	-	-	3.215
Dense glass for achromatic uses	-	-	-	3.437
The concave of an achro- matic lens	-	-	-	3.436
Calcareous spar (calc aera- ta) from the same piece	-	-	-	2.711 to 2.726
Ponderous spar or barytes vitriolata	-	-	-	4.474
Quartz	-	Muschenbroek	-	2.763
Rock crystal	-	Muschenbroek	-	2.650
Diamond	-	Muschenbroek	-	3.456 to 3.654
Rain-water	-	-	-	1.000
Distilled water	-	Muschenbroek	-	0.993
River water	-	Muschenbroek	-	1.009
Sea water	-	Muschenbroek	-	1.030
Saturate solution of sea-salt	-	Muschenbroek	-	1.244
Concentrated vitriolic acid	-	Bergman	-	2.125
Concentrated nitrous acid	-	Bergman	-	1.580
Concentrated muriatic acid	-	Bergman	-	1.150
Concentrated fluor acid	-	Bergman	-	1.500
Oil of amber	-	Muschenbroek	-	0.978
Oil of sweet almonds	-	Muschenbroek	-	0.928
Oil of olives	-	Muschenbroek	-	0.913
Naptha	-	Muschenbroek	-	0.708
Rectified spirit of wine	-	Muschenbroek	-	0.866
Alcohol	-	Muschenbroek	-	0.815
Ether	-	Muschenbroek	-	0.732
Air at the earth's surface	-	Muschenb.	-	0.001 $\frac{3}{4}$ to 0.001 $\frac{1}{4}$
Air. Barometer at 30 in.	-	-	-	-
Thermometer 32°	-	Atwood	-	0.001279

C H A P. III.

OF THE MOTION OF FLUIDS WHICH ARISES FROM
THE PRESSURE OF THEIR SUPERINCUMBENT
PARTS.

THE pressure of fluids being shewn to be in pro- x
portion to their depths (3, H) it will not be diffi-
cult to find the celerities with which they spout
forth from small apertures in the sides or bottoms
of vessels.

For this purpose let us suppose $PQSR$ (fig. 120)
to be a prismatic column of any fluid that passes
through a hole in the bottom of the vessel $FHIG$.
If the height PQ be assumed indefinitely small, the
pressure by which the velocity is produced may be
esteemed constant, because the column $OPRV$,
whose weight (5, Q) is the measure of that
pressure, does not acquire any definite increase
during the passage of the column through its height
 PQ . The weight of the column $OPRV$ exceeds the
weight of the column $PQSR$ in the same propor-
tion as the height PO exceeds the height PQ , and
consequently the action or pressure exerted on the
column $PQSR$ exceeds its mere gravity in the same
proportion. Therefore, whatever may be the final
velocity, or velocity of emission, produced in the
column $PQSR$ in passing through PQ , it will be
required, in order to produce an equal final velo-
city by the mere action of gravity, that the same

- ~~column~~ should descend through a space proportionably greater as this last is less than the former force (1, 36, H), namely through a space equal to $\sqrt{P O}$. That is to say, the velocity of any fluid issuing from a hole in the bottom of a vessel is equal to that which would be acquired by a body falling freely by its gravity through a space equal to the perpendicular height of the fluid above the hole.
- z And because fluids press equally every way at equal depths (4, N), this theorem holds good likewise with respect to fluids that spout through apertures at the sides of vessels, or with any obliquity whatsoever.
- A Hence the motions of spouting fluids may be reduced to rule. For every part of the projected stream being considered as a body in motion, thrown with a given velocity and direction, the same principles will be equally applicable to spouting
- B fluids and to projectiles of any other kind. Thus if the fluid spout directly downwards, its velocity in any point of its course will be equal to the velocity of emission added to that which it would have acquired by gravity in its fall from the aperture; or, (20, Y) which is the same thing, its velocity will be the same as if it had fallen from the surface of the fluid. If it spout directly upwards, it will (1. 31, P. II. 20, Y) proceed with an uniformly retarded motion, which will carry it to the level of the surface of the fluid in the vessel. If it spouts in any other direction, its course will be nearly a parabola (1. 97, U).

On these considerations depends the performance c
of fountains; for the construction of which there is provided a reservoir, elevated considerably above the plane in which the fountain is to be made. A pipe, communicating with the reservoir, is conveyed to the middle of a basin, and by means of a perpendicular spout, called the *ajutage*, throws the water up in the air to a height which is in the level of the surface of the water in the reservoir.

But in applying these observations to practice, d
there are many circumstances that tend to diminish the quantities of motion. There are few fluids that have not a considerable degree of cohesion or tenacity, which prevents their parts from moving as freely as otherwise they would have done; and the friction against the sides of tubes very much retards the motion of the included fluids, if the tubes be long, small or crooked, and the velocity great. The air which, extricating itself from the water, occupies the upper parts of bent pipes, is often a great obstacle to the course of the water, and not unfrequently stops its progress entirely. In fountains, especially where the fluid is thrown perpendicularly upwards, the part that is falling rests upon the ascending column, and prevents its arriving at the height its motion would have carried it to; besides which, the resistance of the air, and other causes, join in increasing the same effect. We must not therefore expect in these more than in other engines, that the per-

formance will equal the theory; yet, it is not difficult to make the proper allowances, so as to find their real effects by calculation; but our purpose, being general, does not extend to the variety of particulars which offer themselves.

C H A P. IV.

OF THE RESISTANCE WHICH FLUIDS MAKE TO BODIES MOVING IN THEM.

- E** WHEN a body is immersed in a mass or quantity of fluid matter, and is in motion, it must separate the parts of the fluid from each other as it moves. If the parts of the fluid be without cohesion or tenacity, this separation will be attended with no difficulty; but if the tenacity be considerable, it will require a considerable force to overcome it. A part of the motion must therefore be lost in producing this effect. And, in the same fluid, the more parts are divided in a given time, the greater quantity of the motion must be lost or employed for that purpose. But a body, moving through an uniform fluid, divides a greater or less number of its parts, in proportion as the velocity of its motion is greater or less.
- F** Consequently, the resistance which an uniform fluid makes, by reason of its tenacity, to a body immersed and moving in it, is in proportion to the velocity of the moving body.

But

But there is another resistance of greater consequence, which fluids make to bodies immersed and moving in them, and arises from the inertia of their parts. For if a body be moved in a fluid, it must give motion to a certain quantity of that fluid, and the reaction of that quantity will destroy part of the motion of the body. Now a body moving through an uniform fluid, gives motion to a greater or less number of its parts, in proportion to the velocity of its motion, and is therefore resisted in the simple proportion of the velocity on that account. Again, a body moving through an uniform fluid, communicates a greater or less quantity of motion to each of its parts, in proportion to the velocity of its motion, and is therefore resisted in the simple proportion of the velocity on that account. On both accounts, then, the resistance which arises from the inertia of the fluid, is in the duplicate proportion of the velocity of the moving body.

When the same body is spoken of, the resistance and retardation follow the same ratio; but, in different bodies, they differ in the same manner as motion and velocity. Resistance signifies the quantity of motion, and retardation the quantity of velocity which is destroyed: for example, if a body be projected with a given velocity in a fluid, and lose half its motion by the resistance in a given time, its retardation will be half its velocity: but if another body of the same bulk, but twice the weight or mass of matter, be projected with a

like velocity in the same fluid, it will be equally resisted; but, having twice the quantity of motion, will only lose one-fourth of its velocity in the same time. Thus, though the resistances be equal, the retardation in the latter instance is only half the quantity of that in the former.

- K In fluids that are not glutinous, the resistance arising from their tenacity is inconsiderable, especially in swift motion; in which case, the resistance from the inertia increasing as the squares of the velocities, while that from the tenacity increases only as the velocities themselves, the proportion of the latter to the former becomes so small that it may be neglected. It is usual therefore, to neglect that resistance which arises from the tenacity of fluids.
- L In like circumstances, the resistances of fluids are as their densities. For the quantity of matter to be moved is in that proportion.
- M If a cylinder be moved through an uniform fluid in the direction of its axis, it will suffer a resistance equal to that of a sphere, whose diameter and velocity of motion in the same fluid are equal to those of the cylinder. For proof of which, suppose the cylinder to be quiescent in the middle of a prismical canal or tube, its axis coinciding with that of the tube. Let this tube be filled with the fluid, and conceive the fluid to be moved through it with a given velocity. Then the fluid will pass between the sides of the tube and the cylinder, and its motion will be impeded by its being reduced to pass
through

through a narrower space. If the sphere be substituted in the place of the cylinder, the space through which the fluid is reduced to pass will be precisely the same, and consequently its motion will be equally impeded. And, because action and reaction are equal, the cylinder and sphere in these circumstances will be equally acted upon by the fluid. Now, let the fluid be supposed quiescent, and the cylinder or sphere moved with the same velocity, and in the contrary direction to that in which the fluid was before moved; and the relative motions of the fluid and immersed body will be the same as before. Consequently, the cylinder and sphere, if moved with equal velocities through a prismatic vessel containing a fluid, will be equally acted upon in the contrary direction to their motions; that is, they will be equally resisted. And, since this equality of resistance does not at all depend on the magnitude of the prismatic vessel, the doctrine may be applied to bodies moving in an indefinitely extended fluid, or fluid contained in an indefinitely large prismatic vessel. It may, therefore, be applied to all bodies in motion which are deeply immersed in any fluid.

Hence it appears, that in order to maintain the uniform motion of a body in a fluid, a constant accession of force is required to overcome the resistance; but as in general, there is no such accession in the motions which are performed about us, they all decay by degrees, and at length terminate.

It

- O It likewise appears, that when a body moves in any fluid, and is acted upon by any constant force, it can obtain but a certain degree of velocity. For, as the resistance increases with the velocity, but in a higher proportion, namely, as the squares, (23, H) it is plain that the resistance at a certain period of the acceleration will become equal to the constantly acting force; after which the body will proceed uniformly, and the constantly acting force will be employed in overcoming the resistance. On this account it is, that bodies that sink in water, or other fluids, by the force of gravity, soon acquire their utmost velocity, and afterwards proceed uniformly. And, in like manner, a ship, when it first gets under way, proceeds with an accelerated velocity, till the resistance of the water becomes in equilibrio with the action of the wind on its sails, but afterwards proceeds uniformly, the force of the wind being entirely employed in overcoming that resistance.
- P In mathematical strictness it is not true, that a body in these circumstances ever arrives at uniformity of motion; for the approach of the resistance to an equality with the impelling force is represented by a converging series, the number of whose terms is infinite, and their sum in any finite time is less than the impelling force: but the latter terms soon become too small to be of any physical consequence.
- Q What is here said of resistance is to be understood of bodies deeply immersed in fluids, the parts

parts of which are compressed together, and non-elastic or incapable of condensation. Friction is likewise neglected. Bodies moving at or near the surfaces of fluids, more especially if they be obtuse, cause the fluid to rise into a heap before the body, at the same time that it subsides at the hinder part. And so likewise, obtuse bodies, moving in elastic fluids, condense that part of the fluid towards which they are moving, while the part from which they recede is rarefied. In these cases the resistances are greater than would be deduced by the principles here treated of*.

* Principia. II. § 8.

B O O K II.

S E C T. IV.

Of the Air or Atmosphere.

C H A P. I.

OF THE GENERAL PROPERTIES OF THE AIR, THE
DIMENSIONS OF THE ATMOSPHERE, AND THE
MEASUREMENT OF THE HEIGHTS OF MOUN-
TAINS BY MEANS OF THE BAROMETER.

- R CONTINUAL experience shews, that we are im-
mersed in a fluid which agitates bodies when it
is in motion; resists the motions made in it; sus-
tains bodies floating in it; and, in short, differs
very little in its general properties from the grof-
ser fluids, great rarity, elasticity, and transparency,
being its distinguishing characters.
- S The whole mass of this fluid, with its contents,
is called the atmosphere; a term made use of when
the effects that arise from its form, magnitude,
density, &c. are considered; but when the fluid
of which the mass is composed is indefinitely spoken
of,

of, with a view to develope its qualities, and consider it independent of the bodies immersed in, or mixed with it, it is called the air, or air..

Air is a fluid, whose particles are not in contact, and repel each other with a force that may be diminished, but cannot be destroyed by any degree of cold known in the vicinity of the earth. For, if the particles were in contact the fluid could not be compressed, and if they did not repel each other, the fluid could not expand when the compressing force is removed. This property of the air may be shewn by various methods: one of the simplest is, to pour a quantity of quicksilver in the tube ABC (fig. 124), closed at A, and open at C. Suppose the tube to be filled with quicksilver to E, then the air inclosed in the leg AB will prevent its rising higher than D. Mark F in the same horizontal line with D, and (6, T) the column DB will be in equilibrio with FB; consequently the quicksilver contained between F and D will not at all press on the air between A and D. But the column EF acting with its whole weight on the quicksilver between F and D causes it to press on the air at D, and condense it. By increasing the quantity of quicksilver the condensation is increased, and it is found, that the spaces into which the air is condensed by different weights are inversely as those weights; or its density is as the pressure it bears.

One of the first objects of enquiry that offer w themselves respecting the atmosphere is its extent

or

or magnitude. Experience assures us, that it is extended over the whole surface of the earth and sea; and it is evident, from the suspension and motion of the clouds, that its altitude is considerable; but the measure of this altitude must be obtained from its effects. Thus, if the specific gravity of the air be found, and also its whole pressure on bodies, it will be easy to discover the quantity of the fluid, and its height, if supposed to be uniformly dense. Another method of discovering the height of the atmosphere is deduced from optical considerations, by observing the effect it has on the light of the Sun.

- x To find the specific gravity of the air, let *AB* (fig. 125) represent a bottle, whose contents are exactly known; for example, suppose it capable of holding two pounds of rain-water; let a valve, opening outwards, be fitted at *A*, and the air be exhausted from within by means of the air-pump, hereafter to be described; let the vessel thus exhausted be weighed in water, or any other dense fluid, in the vessel *MN*, as represented in the figure, after which let the air be admitted. An additional weight of about $14\frac{1}{2}$ grains will be required to restore the equilibrium: therefore, the air contained in the vessel *AB* weighs $14\frac{1}{2}$ grains, the proportion of which to two pounds is 1 to 800, or $\frac{1}{4}$ to 1000.

- y In this experiment the vessel *B* is immersed in water, that the fulcrum of the scales being less loaded, may turn with less friction, and consequently

quently be more sensible. It is attended, however, with some difficulties; the chief of which consists in the attraction or repulsion exerted at the surface of the water, and this is considerable enough to induce some philosophers to weigh the bottle without immersing it.

The specific gravity of air, being thus discovered, ^z its pressure may be found by the Torricellian experiment, so called from its inventor Torricellius. Let AB (fig. 126) represent a glass tube of the length of 35 inches or upwards, closed at the end A, and open at B, fill the same with quicksilver, and close the orifice at B with the finger, or otherwise: immerse the end B in the vessel of quicksilver CD, and remove the finger from the orifice; the quicksilver will then subside to N in the tube at the height of about 30 inches.

This phenomenon is readily explained on the ^A common principles of hydrostatics: for which purpose it must be remembered, that the pressure a body, immersed in the vessel CD, would sustain, is not only that which arises from the weight of the quicksilver, but likewise from that of a column of the atmosphere, incumbent on its surface; so that every column of the quicksilver presses with a force that exceeds its own weight. When the tube is inverted into the vessel of quicksilver, the surface of the column it contains being defended from the pressure of the atmosphere, by the closure at A, can press downwards with no more than its own weight; and will, therefore, be in equilibrio with the pressure
the

the quicksilver in the vessel exerts against its descent, then only, when it is so much longer, that the additional quicksilver may be equal to the additional weight which a similar column in the vessel receives from the pressure of the atmosphere; that is to say, the pressure of the atmosphere on any given surface is equal to the weight of a column of mercury, whose base is the given surface, and height equal to that at which it stands in the Torricellian tube; and this pressure is the weight of a column of air, whose base is the given surface, and height equal to that of the atmosphere. Or, generally, because the bases may be supposed not to vary, the pressure of the atmosphere, is as the height of the mercury in the tube.

An instrument consisting of a Torricellian tube, with a scale adapted for measuring the heights of the mercury, is called a Barometer.

c It has been shewn, that when the air is condensed, its density is in proportion to the weight that compresses it (29, v). By means of the Torricellian tube it may be observed, that the same proportion obtains when it is rarefied by taking off part of the weight of the superincumbent atmosphere. For, in any elastic fluid at rest, the spring must equal the compressing force (1. 22, R); and if any part of that force be taken away, it must expand till the spring becomes equal to the remainder; which will happen if the elasticity of the fluid be weakened by expansion. And since the pressures of fluids are as their heights (3, H)

the pressure of the mercury in the tube AB (fig. 126) will be equal to that in the tube AB , when the mercury rests at n in the same horizontal line with N . Now, if a bubble or small quantity of air be admitted into the tube AB , it will depress the mercury below the mark N , till its spring, and the weight of the mercury remaining in the tube, be in equilibrio with the pressure of the atmosphere; that is, if the mercury be depressed to M , that part of the weight of the atmosphere which corresponds with the quantity of mercury MB , will be sustained by the weight of the mercury, and the remainder MN will be sustained by the spring of the included air. The included air then, being pressed by a weight less than that of the whole atmosphere, becomes rarefied or expanded. By variously inclining the tube, or by immersing its lower end to greater depths in the basin, the included air may be made to bear more or less of the weight of the atmosphere, as may be gathered by measuring the perpendicular altitude of M above the surface of the quicksilver contained in the vessel CD , and subtracting it from the altitude BN , which corresponds with the weight of the whole atmosphere, and its contraction or dilatation observed: whence it appears, that the density of air, though greatly rarefied, is proportional to the compressing force.

If two columns of uniform fluids, whose specific gravities differ, be equal in weight, and stand on equal bases, their heights will be reciprocally as their specific gravities (4, L. M. 6, T). The specific

gravities of quicksilver and air are respectively
14019 and $1\frac{1}{4}$: therefore,

As the specific gravity of

air, - - - -

Is to the specific of mer-

cury, - - - - 14019

So is the height of the

column of mercury, - 30 inches,

To the height of an equal

column of air - - 336456, or $5\frac{1}{4}$ English
miles.

z This would be the height of the atmosphere, if it were uniformly of the same density; but as that is not the case, on account of the elasticity which causes the upper parts to expand in proportion as the weight of the superincumbent parts becomes less, the altitude must be much greater.

r The density of the air in that part of the atmosphere in which we live being shewn to be as the weight that compresses it, it is plain, if the constitution of the air in the superior regions be of the same kind, that its density at any altitude will be as the weight or quantity of the superincumbent air. Suppose A m (fig. 127) to be a column of the atmosphere, and imagine the same to be continued at pleasure beyond m, so as to reach its utmost limits. Let this column be divided into an indefinitely great number of equal parts, A b, b c, c d, &c. and the quantity of air contained in any one of those parts, or its density, will be in proportion to the quantity of air which is superincumbent on
that

that part. Now, the difference between the quantities of air incumbent on any two contiguous parts is the quantity contained in the uppermost of those parts; that is, for example, the quantity superincumbent on d is less than that which is incumbent on c by the difference or part cd : therefore the quantities contained in the equal parts or divisions are the differences between the incumbent masses of air taken in a regular succession; and these quantities or differences have been shewn to be in proportion to the incumbent masses. * Now, it is demonstrable, that if any succession or series of magnitudes do increase or decrease in such a manner, that the differences shall be in proportion to the magnitudes themselves, then those magnitudes, and consequently their differences, shall be in a continued geometrical progression: whence it follows, that the densities or quantities of air contained in the equal divisions or parts ab , bc , cd , &c. must decrease in a continued geometrical progression.

On these considerations is founded the barometrical method of measuring the elevations of mountains, or other eminences. The principles made use of may be explained as follows:

If a barometer were carried upwards with an uniform motion through the column of air Am ,

* Let a , b , c , d , &c. be magnitudes, whose differences are as the magnitudes themselves.

That is

Then

And

$$\left| \begin{array}{l} a-b : b :: b-c : c :: c-d : d, \text{ \&c.} \\ a-c = b-b, b-d = c-c, \text{ \&c.} \\ a : b : c : d, \text{ \&c.} \end{array} \right.$$

D 2

(fig.

(fig. 127) its elevation above the surface of the Earth would increase by the continual addition of the equal spaces $A b$, $b c$, $c d$, &c. so as to be successively represented by the natural series of the numbers 1, 2, 3, &c. but the mercury in the tube would continually descend so as to pass through heights that would be proportional to the pressures or densities of the air (52, B, c) at A , b , c , d , &c. **K** that is to say, while the elevations above the surface of the earth increase arithmetically the heights of the mercury in the tube will decrease in a continual geometrical series (35, o).

L Now, it is well known, that if a continued geometrical series, beginning with unity, be ranged in order, with an arithmetical series, beginning with 0, or a cypher, the numbers of the latter series will be the logarithms of the correspondent numbers of the other. Such are the numbers before us; for the greatest density of the air, or greatest height of the mercury, may be called unity, and answers to an elevation of 0, or nothing above **M** the Earth's surface. The elevations above the Earth's surface will therefore be the logarithms of the heights of the mercury in the barometer.

N If therefore we were provided with a table of logarithms, or an arithmetical series of known unities or measures, adapted to that geometrical series which expresses the gradual descent of the mercury, while it is carried with an uniform motion upwards, the differences of the logarithms of any two given heights of the mercury would in fact

fact be the difference of the elevations above the Earth's surface, or it would be the perpendicular space through which the barometer had been carried, in order to produce that descent of the mercury.

But as there is no such table in being, it would become necessary to compute directly from the properties of the geometrical series, if there were not a method of applying the common tables of logarithms to this purpose. It is a property of all logarithms, that if the difference between the logarithms of two numbers be taken in one set of logarithms, and the difference between the logarithms of the same two numbers be taken in logarithms of another form, the proportion between these two differences will be constant for all pairs of numbers so taken*. From hence if the difference of two elevations be experimentally found, and the respective heights of the mercury observed at each, it will not be difficult to deduce any other difference of elevation from observations of the heights of the mercury at each.

* In the following series,

O. 3. 6. 9. 12. 15. logar.

O. 2. 4. 6. 8. 10. logar.

1. n. n^2 n^3 n^4 n^5 numbers.

it is obvious, that the logarithm of any number in one series has a constant ratio to the logarithm of the same number in the other series. And the differences between the logarithms of two given numbers in the two series of logarithms will have the same constant ratio, as being the logarithms of one and the same number, namely, the quotient of those two numbers.

P An example will render this clear. Suppose the height of the mercury in a barometer be 29.565 inches, and the height of the mercury in another barometer, placed at an elevation of 710 feet above the former be 28.770 inches, it is required to find the difference of elevation of two barometers, whose mercurial columns stand respectively at 28.9 inches, and 27.5 inches.

Q If the altitude of the mercurial column, 30 inches, be taken as unity, or the first term of the geometrical series, the two first altitudes will become fractions $\frac{29}{30} \frac{565}{1000}$, and $\frac{28}{30} \frac{770}{1000}$ of that unity, the number 710 being the difference of the logarithms, or correspondent terms of the arithmetical series of elevation, taken in feet. Take now the difference of the common logarithms of those fractions, or, which is the same, the difference of the logarithms of their numerators, thus:

$$\begin{array}{rcl}
 29.565 \text{ its logarithm,} & - & 1.4707779 \\
 28.770 \text{ its logarithm,} & - & 1.4589399 \\
 \text{Difference,} & & \underline{.0118380}
 \end{array}$$

R And this difference .0118380 will bear the same proportion to the difference of elevation 710, as the difference of the common logarithms of any other two altitudes of the mercury will be to the difference of elevation between them (37, 0): so that with respect to the thing required,

$$\begin{array}{rcl}
 \text{From the logarithm of } 28.9 & - & 1.4608978 \\
 \text{Take the logarithm of } 27.5 & - & 1.4393327 \\
 \text{The difference is} & & \underline{.0215651}
 \end{array}$$

And as .0118380 : 710 :: .0215651 : 1294 feet.

As

As the two first terms are of constant use in these computations, it will be advantageous to reduce them to the simplest expression; thus, as $.0118380 : 710 :: 1 : 60000$ nearly; so that, instead of working the proportion with the two first terms, it will be sufficient to multiply the difference of the logarithms by 60000, and the product will give the elevation in feet of one barometer above the other.

But to multiply this difference by 60000 is the same as to multiply it by 10000, and by 6. The multiplication by 10000 is effected by moving the decimal point four places farther to the right: whence it is seen, that the decimal point being removed four places to the right, converts the difference of the logarithms into a number that requires to be multiplied by 6 to reduce it into feet. The number itself is therefore the height in fathoms and decimal parts:

Consequently, the shortest general rule for measuring heights by the barometer is, take the difference of the logarithms of the heights of the mercury at both stations, and the four first figures following the decimal point will be the fathoms, and the rest a fraction of a fathom, expressing the elevation.

It is evident, however, that this rule supposes w the specific gravity of the mercury to remain unaltered, because its height could not otherwise be a settled measure of the densities of the air that sustains it. It is likewise implied, that the density of

the air is subject to no other change than may arise from its diminished compression in ascending towards the upper regions of the air: but neither of these positions can be admitted in the actual practice. For all bodies expand and occupy larger spaces when their temperature is increased. The mercury in the barometer, when heated, will be specifically lighter, and will consequently ascend from that cause, even though the pressure of the air should remain unchanged: and the air, when expanded by the same agent, will not diminish its pressure after the usual ratio in ascending: or, if the same geometrical series be supposed to be retained, the unity of its logarithms will be greater than before, and the general rule, (39, v) instead of giving fathoms, will give a number of some larger measure. Thus, we see, that the rule can be true only with respect to air of a given temperature, and that in all other cases it will require to be corrected.

By a very valuable set of experiments it is found, that the mercury in a barometer changes its altitude by heat, according to the following table:

If the mercury in the barometer stand at 30 inches when the temperature is 32° ; its changes will be for every degree,

between	between	between	between
0 and 32°	32° and 52°	62 and 72	72 and 92
falls 0.0034 inch.	rises 0.0033	rises 0.0032	rises 0.0031

In order therefore that we may know the effect of the air's pressure on the barometer, it is required, that

that its height should be corrected by the addition or subtraction of these quantities, according to the number of degrees of temperature above or below 32° , and in proportion to its height.

It is also pretty well established from barometrical observations, and from experiments made with air of various densities, that its expansions by heat are as in the following table. The height of the mercury is taken to be the mean between the heights at the extremities of the column of air, and the column entitled correction shews the expansion or diminution of the column of air in thousandth parts of the elevation given by the general rule (39, v).

Mean height of BAROMETER 30 inches.

Mean Temperature of the air.		Correction.	Difference for 1 inch barom.
92 ^o	Add to Logarithmic elevation.	156.381	6.0925
82		131.188	5.111
72		105.047	4.0925
62		78.427	3.0555
52		51.335	2.0000
42	Subtract	25.193	0.9816
32		0.	0.
22		24.242	0.4722
12		47.532	0.9259

The philosopher who undertakes to measure heights barometrically should be provided with two portable barometers, of the best construction; on which he may read off the height of the mercurial columns to the 500th part of an inch; each barometer

meter must be fitted up with an attached thermometer, set in the wooden frame in the same manner as the barometer-tube is. It is convenient that the ball of each thermometer be nearly of the same diameter as the barometer-tube: he should also be provided with two other thermometers, detached from the barometers. One barometer with its attached and detached thermometers is to be placed in the shade, on the eminence, whose height is required, while the other remains in the plain below. These must be suffered to continue in their places at least a sufficient time for the detached thermometer to acquire the temperature of the air, that is to say, till it ceases either to rise or fall. The observer on the eminence must then make an observation of the height of the mercurial column, and also of the temperatures exhibited by the attached and detached thermometers at the same time that the observer in the plain performs the like with the instruments below. It will tend much to diminish the errors, if three or more sets of observations be taken at each station after short intervals of time, and the mean of the whole be made use of as the true observation.

- E The nearer these directions are adhered to the more accurate will be the result; but they will admit of considerable deviations in the practice. In cases where better instruments cannot be had, any well-made portable barometer, graduated so as to shew the true fall of the mercury, may afford observations by no means to be despised. For a small

small error in the position of the zero, or lower point, from which the scale of inches begins, provided the point be fixed, will not sensibly affect the result; and the attached thermometer may be dispensed with, if an hour or more be allowed for the mercury in the barometer to acquire the temperature of the surrounding air, which is shewn by the detached thermometer. A single barometer may supply the place of two, if the observations can, within any moderate space of time, be made first in the plain, then on the mountain, and again repeated on the plain: because it may reasonably be presumed, that if the two sets of observations on the plain agree together, the common density of the air below has not changed during the operation. The observations being made, the height may be deduced according to the following summary of the contents of the preceding pages:

First. Reduce the height of the mercury in each barometer to the height it would have stood at in the temperature of 32° . This is done by adding to the height, or subtracting from it the quantity indicated in the table (40, z, A) for that purpose, according to the number of degrees the attached thermometer stands below or above 32° , and the observed height in the tube.

Secondly. Take the difference of the logarithms of the reduced heights of the mercury in each barometer; of this difference, the four first figures on the left will be the logarithmic elevation in fathoms, the remaining figures being a decimal. This will be

be the true elevation, if the mean between the temperatures indicated by the detached thermometer be 32° .

- H Thirdly. But if the mean temperature of the column of air, as indicated by the detached thermometers, be above or below 32° ; find the mean between the two altitudes of the mercury; extract from the table (41, c) the two numbers in the column of differences that range opposite the two temperatures, between which the mean temperature of the column of air lies; multiply each by the number of inches (and parts, if the elevation be great) which the mean altitude of the mercury differs from 30 inches. Subtract these products from the respective opposite numbers in the column of corrections, if the mean altitude of the mercury be less than 30 inches, but add, if it be greater. Find the difference between these two remainders or sums, and multiply it by the number of degrees by which the mean temperature exceeds the lower of the two adjacent temperatures in the table. Divide this product by 10, and add the quotient to the least of the two remainders or sums, last mentioned. The sum will be the true correction in thousandth parts of the logarithmic elevation. Reduce it into fathoms, by multiplying it into the logarithmic elevation, and dividing by 1000. This quotient being added to the logarithmic elevation, if the mean temperature exceeds 32° , or subtracted, if it fall short of 32° , will give the true elevation or perpendicular distance between the two barometers.

Example.

Example. Suppose the following observations ¹ to be made, it is required to find the elevation, or vertical distance between the barometers.

Lower station.	Upper station.
Caernarvon quay.	Peak of Snowdon.
Height of Mercury, 29.976 in.	26.289 inches.
Attached thermometer, $62\frac{1}{4}^{\circ}$	- $46\frac{1}{2}^{\circ}$
Detached thermometer, 62	- 46

The computation. By the table (40, z) the κ reduction for the lower barometer comes out 0.1, which, subtracted from 29.976, gives 29.876. By the same table, the reduction for $46\frac{1}{2}^{\circ}$, with a column of 26 inches, comes out .042, which, subtracted from 26.282, leaves 26.240 inches. Now, the logarithms of the reduced altitudes, 29.876, and 26.240, are 1.4753225, and 1.4189638, the difference of which is .0563587, or (43, G) 563.587 fathoms.

The mean temperature between 62° and 46° is ^L 54° , and consequently the logarithmic result will require corrections by the second table. The mean between the two barometrical heights is 28 inches, or 2 inches below 30. The two numbers in the column of difference opposite the temperatures 52° and 62° are 2.0000, and 3.0555; these, multiplied by the number of inches, or 2, give 4.0000 and 6.111; the number 4.0000, subtracted from its opposite in the column of correction, 51.335, leaves 47.335; and the number 6.111, subtracted from 78.427, leaves 72.316; the difference between these

46 THE COMPUTATION AND ADVANTAGES

these remainders 47.335 and 72.316 is 24.981, which, multiplied by 2, the number of degrees by which the mean temperature 54° exceeds 52° , the lower of the two adjacent temperatures in the table, gives 49.962. This product, divided by 10, is 4.9962; which quotient, added to 47.335, the least of the two remainders, makes 52.331, the true correction in thousandth parts of the logarithmic elevation.

M The true correction 52.331, being multiplied by the logarithmic altitude 563, produces 29462.353; this divided by 1000 affords a quotient of 29.462353; which is the true correction in fathoms, to be added to the logarithmic elevation, because the mean temperature exceeds 32° : the sum, namely, 563.587, added to 29.462353, makes 593.049353 fathoms, or 3558.297118 feet, for the true elevation required*.

N The intelligent reader will readily perceive, that though the decimals in this computation are mostly retained, yet, it will in general be sufficiently exact, and much less operose, if only the two first decimal figures of any number be retained.

O The advantages of this method, compared with the geometrical method of measuring elevations are,

* This method, which is taken from Col. Roy's excellent paper in the 67th volume of the Philosophical Transactions, may be rendered more easy in the practice, by extending the tables so as to give the corrections at sight, as in some measure done in the original; but the brevity of the present work prevented their being copied here.

first,

first, the instruments are neither very expensive nor even difficult for an ingenious philosopher to make in any country where he can procure quicksilver and glass tubes; but the geometrical method demands instruments of considerable price, which can scarcely at all be constructed by the most ingenious person who is destitute of the tools, and unacquainted with the artifices required to render them correct. Secondly, The barometers require no other adjustment than to observe previously, whether they agree, and to allow for their difference. The barometrical observations are likewise easily made; whereas, on the contrary, the previous adjustment and subsequent use of instruments for measuring angles require a degree of precision and skill not usually obtained without practice. Thirdly, The error of observation in the barometrical method for all elevations is nearly a constant quantity, never amounting to so much as half a fathom for a mistake of the 500th of an inch; but any error either in the measurement of lines or angles proportionally affects the result; so that the greater the elevation required to be measured, the larger the quantity of error. Fourthly, The barometrical observations require no particular circumstances of advantage, either in the figure or situation of the mountains required to be measured, nothing more being required than that both stations be accessible. These observations, and the computation, are performed after the same method in all cases; but in the geometrical method, if the horizontal distance

of

of the two stations be considerable, or if there be not a convenient plain for measuring a fundamental base, the operation becomes very complicated, and the chance of error is multiplied.

- P It must not, however, be disguised, that the principles of the geometrical method are established and sure, and that an extreme degree of exactness may be obtained in this way by good instruments in the hands of a skilful observer. Whereas the modifications of the atmosphere, with respect to the effect which exhalations of various kinds, and the greater or less abundance of the electric matter, may have in expanding the air, without changing its temperature, are not yet sufficiently known to render the corrections altogether as perfect as might be wished. Future observations must point out these, and in the mean time it is to be remembered, that the elevations determined by the barometer, when the extreme temperatures of the column of air do not greatly differ, and when the air is cold and dry, are most to be depended on*.

* For a more full account of this curious subject, consult De Luc's *Recherches sur les Modifications de l'Atmosphere*. Sir George Shuckburgh's valuable *Observations made in Savoy*, in order to ascertain the height of mountains by means of the barometer, inserted in the *Philosophical Transactions*, vol. 67. with Col. Roy's, and Mr. de Luc's papers, in the same volume: also Damen's *Dissertatio Physica et Mathematica de Montium Alitudine barometro metienda*; and the authors by him cited.

C H A P. II.

OF THE REFRACTIVE POWER OF THE AIR; AND
THE CAUSE OF TWILIGHT.

THAT the celestial space or heavens is either *Q* nearly or absolutely vacuous, appears from the small resistance the planetary bodies suffer in their motions; such resistance, if it obtain at all, being too minute to be clearly ascertained by any observations we are in possession of. Light therefore, when incident on our atmosphere, passes from a rarer to a denser medium, and ought, according to the principles of optics, to be refracted towards the perpendicular (*1. 262, A*). And this is accordingly the case. Let the circle *A B C* (*fig. 130*) *R* represent a section of the Earth, and the external concentric circle the surface of the atmosphere; let *H N* be the sensible horizon of a place *A*, and *s* the Sun beneath the horizon; then a ray of light incident on the surface of the atmosphere at *i*, will, instead of proceeding to *a*, be refracted towards the perpendicular *i s*, and that continually the more as the density of the medium becomes greater, so that it will arrive at *A* after passing through the curve *i A*; and a spectator at *A* will behold the Sun in the line of the last direction of the ray, namely, in that of *A s*, the tangent to the curve. The apparent elevation which a celestial body suffers when its rays

fall with the greatest obliquity, to wit, when it is seen in the horizon, is about thirty-three minutes of a degree: at other altitudes the differences between the true and apparent places are less, the incidences and refractions being less considerable.

T Hence it comes to pass, that we see the celestial bodies for some time after they are set, and before they rise in reality, by which means we enjoy about three days in the year more day-light than otherwise we should: but in the northern parts, where the sun rises and sets more obliquely, and the atmosphere being condensed by cold, refracts more strongly, the difference is much greater.

U The refraction, as well as all the other phenomena produced by the atmosphere, are variable, as the density of the air changes. This variation renders the observation of low altitudes uncertain, as the allowance for refraction cannot be collected with great precision from any tables. The trigonometrical admeasurement of the heights of lofty mountains is likewise rendered less accurate from this cause.

V A method of discovering the height of the atmosphere is deduced from observations of the morning and evening twilight. Notwithstanding the very great transparency of the air, it may be rendered visible by means of the rays of light reflected from its parts in all directions. This effect is seen when the beams of the Sun are admitted into a room through the window-shutter, and may frequently be observed when the Sun shines through the chasms

chasms or openings in a dark cloud: from which cause it happens, that those bodies which emit a very small quantity of light are not to be discerned in this stronger light. In the day-time the stars *w* are invisible, and the flame of a candle can scarcely be seen in the sun-shine: were it not for this illumination the sky would appear black; and the shady sides of objects would be of a dark colour, nearly the same as at midnight.

The sun shining on the globe of the earth can *x* illuminate but one hemisphere at once, as has already been shewn; but it is not so with the atmosphere which environs the globe. Thus, the illuminated part of the globe terminates at *D* and *d*, (fig. 128) but the atmosphere is enlightened as far as *B* and *b*. In consequence of this it happens, that those parts which have already entered into the dark hemisphere, and to which therefore the Sun is set, must still enjoy a degree of light that continues as long as any of the enlightened part of the atmosphere remains in view. This light, which *y* gradually decays after sun-set, or increases before sun-rise, is called the 'twilight. Let *A H C D d b* (fig. 129) represent a section of the Earth in the plane of the Sun's azimuth, and let the space contained between the concentric circles represent the atmosphere: then, the Sun's rays in the directions *s B*, *s b*, will illuminate half the globe *D C d*, and the atmosphere will be enlightened as far as *B* and *b* on each side within the dark hemisphere; which enlightened part, so long as it continues above the

E 2

horizon

horizon of any place, will cause a twilight at that place. The ray $s d B$ is a tangent to the Earth at D , and meets the circumference of the atmosphere at B . From B draw the line $B h$, a tangent to the Earth at A , which continue towards N ; $h N$ will then represent the horizon, in which the extreme point B of the enlightened part of the atmosphere will be situated; that is, twilight will be just beginning or ending at the place A . The angle $s B N$, which is equal to the angle $A E D$, will be the angle of the Sun's depression beneath the horizon $h N$; and the angle $A E B$ is the half of $A E D$. Hence, if the depression of the Sun beneath the horizon, and the semidiameter of the Earth be known, it will be easy to find the height of the atmosphere. For, in the right angled triangle $A B E$,
As the sine complement of half

the Sun's depression - - $A E B$ $8^{\circ} 30'$

Is to the Earth's semidiameter - $A E$ 3437 miles,

So is radius - - - sine 90°

To the hypotenuse - - - $E B$ 3475 miles.

The difference between which and the semidiameter of the Earth, is the line $h B$, or height of the atmosphere, 38 geographical, or 44 English miles. The angle of the Sun's depression is known by the time elapsed between the beginning or end of twilight, and the rising or setting of the Sun; and it is judged to be twilight so long as the illumination of the atmosphere prevents the smaller fixed stars from appearing. It is also observed, that the evening are always longer than the morning twilights,
which

which must arise from the rarefaction of the air over the place, after the day's sun-shine. A similar difference is observed between the twilights of summer and winter.

This explanation is sufficient to shew the cause of the twilight. But in strict computation the refraction to which the light is subject three times before it comes to the eye should be allowed for, and will somewhat diminish the height deduced.

C H A P. III.

CONCERNING THE CAUSES BY WHICH THE SPRING OF THE AIR IS ALTERED, AND WINDS ARE PRODUCED.

THE expansion of air by heat, while the pressure remains the same, has already been taken notice of (40, x). Heat therefore increases its spring, as may be shewn by the following experiment:

Let $A D B$ (fig. 131) represent a hollow-glass ball, having a narrow bent tube $A C G E$ affixed to it. The lower part of the bent tube, and part of the ball, is filled with mercury, as in the figure; the surface $A B$ within the ball being on the same horizontal line with the surface at c in the tube. The parts of the mercury will then be in equilibrio, the external surface c being pressed by the weight

of the atmosphere, and the internal surface *AB* being pressed by the spring of the included air, which is equal to that weight. But if the ball be immersed in boiling water, the increased spring of the included air pressing on the surface *AB*, will raise the mercury from *c* to *G*, and there sustain it, namely, at the height of $8\frac{1}{2}$ inches, when the mercury in the Torricellian tube stands at 30 inches. And as the contained air is not sensibly dilated by the extrusion of so small a quantity of mercury, the sustentation may be regarded as the entire effect of its spring. The spring of the included air at the heat of boiling water is therefore not only equal to the weight of the atmosphere, but likewise to an additional pressure of more than $\frac{1}{3}$ of that weight.

- E** By the same instrument, it is found, that the elasticity of the air is weakened by immersion in very cold or freezing mixtures. And conclusions similar to these may be made by various methods, which the attentive learner will readily discover.
- F** In the foregoing experiment the air was prevented from expanding, in consequence of its increased spring, by the pressure of the mercury, but if, instead of putting mercury into the ball, a small quantity be made to hang in the tube, as at *GH*, it will by its motion indicate the dilatation or contraction of the included air. By a method similar to this it is found, that from the point *o* in Fahrenheit's thermometer to the heat of boiling water, or 212° , common dry air expands so as to occupy an additional space more than before, equal to the fraction
- tion

tion .48421 of its former bulk. But the expansions of moist air are much greater *.

It will not be difficult from these experiments to point out the causes of many phenomena that happen in the air. For, if any part of the air be either heated, or charged with vapor, it will expand, and in consequence of that expansion become specifically lighter than before. It must, therefore, by the laws of hydrostatics, ascend, and the circumambient air must press in on all sides to supply its place. Hence the cause of the ascent of smoke in a chimney. The air which passes through the fire, or comes within a certain distance from it, is rarefied, and ascends, giving place to the cold air that presses in: this in its turn becomes rarefied, and the ascending current of air continues as long as the fire is kept up, the wind drawing from all parts towards the chimney.

If the fire were in the open air, the heated air would still ascend in a current, and the cooler air press in on all sides; that is to say, a wind would be generated, which would constantly blow towards the fire. The quantity of air rarefied by any fire we can make is so small, that the wind produced by that means is too inconsiderable to be perceived at any great distance from the fire; but the rarefactions

* Muschenbroek's *Cours de Physique* may be consulted for an abstract of what has been done respecting the expansion of air by *Amentaux*, and others. But the most copious and valuable set of experiments are those of Col. Roy, in the *Philosophical Transactions*, part 2, for the year 1777.

arising from natural causes are sufficient to produce all the winds that agitate the atmosphere.

- K** The sensible horizon is not only divided into 360 degrees, like other great circles, but also into 32 equal parts, called points of the compass, which are again subdivided into halves and quarters. The points of the compass have each a separate name. The points of intersection between the meridian and the horizon are termed North and South; and two other points, at the distance of 90° from the North and South, are termed East and West: these four are denominated cardinal points. The intermediate points take their names from the cardinal points between which they are situated, as in the figure, where the initial letters N. S. E. W. (fig. 132) stand for the words North, South, East, West.

- L** A wind is named from the point of the compass from which it blows.

- M** The different winds may, with respect to their direction, be reduced into three classes, viz. general, periodical, and variable winds.

- N** General winds blow always nearly in the same direction. In the open seas, that is, in the Atlantic and Pacific Oceans, under the equator, the wind is found to blow almost constantly from the eastward; this wind prevails on both sides of the equator to the latitude of 28° . To the northward of the equator, the wind is between the North and East, and the more northerly the nearer the northern limit; to the southward of the equator, the wind

wind is between the South and East, and the more southerly the nearer the southern limit.

Between the parallels of 28° and 40° south lat. in that tract which extends from 30° West to 100° East longitude from the meridian of London, the wind is variable, but by far the greater part between the N. W. and S. W. so that the outward bound East India ships generally run down their casting on the parallel of 36° south.

Beyond the northern limit of the general wind in the Atlantic Ocean, the westerly winds prevail, but not with any certainty of continuance.

Near the western coast of Africa, within the limits of the general wind, the winds are found to be deflected towards the shore to such a degree, that they are found to blow from the N. W. and S. W. quarters for the most part, instead of the N. E. and S. E. as is the case farther out at sea.

The general winds are usually called trade-winds.

In the Atlantic Ocean, the S. E. trade-wind extends as far as 3° north, and the N. E. trade-wind ceases at the 5th degree N. In the intermediate space are found calms, with rain, and irregular uncertain squalls, attended with thunder and lightning. But this space is shifted farther to the northward or southward, accordingly as the Sun's declination is more northerly or southerly.

Periodical winds are those which blow in a certain direction for a time, and at stated seasons change and blow for an equal space of time from the opposite point of the compass. These may be divided

divided into two classes, viz. monsoons, or winds that change annually; and land and sea-breezes, or winds that change diurnally.

u While the Sun is to the northward of the equinoctial, that is to say, in the months of April, May, June, July, August, and September, the wind blows from the southward over the whole extent of the Indian Ocean; namely, between the parallels of 28° N. and 28° S. latitude, and between the eastern coast of Africa and the meridian which passes through the western part of Japan. In the sea between Madagascar and New Holland, the S. E. wind prevails as far as the equator, where it is deflected, and blows into the Arabian Gulf and Bay of Bengal from the S. W. Between Madagascar and the main land of Africa, a S. S. W. wind obtains, and coincides with the S. W. winds in the Arabian Gulf. To the northward of New Holland, the S. E. wind is predominant, but varies very much among the islands; and between the peninsula of Malacca and the Island of Japan, a S. S. W. wind prevails. All this is to be understood for the aforementioned months.

v But in the other months, October, November, December, January, February, and March, a remarkable alteration takes place. In the sea between Madagascar and New Holland, the S. E. wind extends no farther to the northward than about the 10th degree of south latitude, the other 10 degrees being occupied by a wind from the opposite point of the compass, or N. W. at the same time that the winds

winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months. These winds are called monsoons, or shifting trade-winds.

These changes are not suddenly made. Some w days before and after the change, there are calms, variable winds, and dreadful storms, attended with thunder, lightning, and rain.

On the greater part of the coasts of lands situated x between the tropics, the wind blows towards the shore in the day-time, and towards the sea in the night. These periodical winds are termed the land and sea breezes, and are much affected, both in their direction and return by the courses of rivers, tides, &c.

Variable winds are those which are subjected to y no period, either in duration or return, and are too well known to need description.

If the air were uniformly of the same density at z the same height, and the lighter parts always reposed upon the heavier, it is evident that, the lateral pressure being equal in every horizontal direction, it would remain at rest. But if, on the contrary, any portion or part of the air were heavier than the rest, it would descend, or if lighter, ascend till the equilibrium was restored, so that either the displaced air would occasion a wind, diverging from a central space, in consequence of the descent or pouring down of the heavier air, or else the air rushing in, would occasion a wind converging to a central space to supply the lighter ascending stream. It A

is

is therefore evident, that any agent that alters the density of a part of the air will produce a wind.

The density of air is changed by compression, and by heat. Its elasticity is increased by the addition of moisture, and electricity may have likewise some effect of the same kind. The compression the air suffers in the natural course of events, is nearly uniform, and experiments are wanting to decide, whether the addition of moisture to air at any of the usual temperatures does not augment its density as much as the increased elasticity diminishes it; neither have any methods been yet devised to shew, whether air in different situations with respect to electricity is altered in its dimensions. In considering the causes of winds, the principal agent to be attended to must therefore be heat.

- c If the Earth did not revolve on its axis, it is plain that the Sun, being stationary over one particular spot, would rarefy the air at that spot: it would consequently ascend by the pressure of the circumambient, and less rarefied air, till it arrived at a region in which the air was sufficiently rare to suffer it to expand on all sides: and thus there would be produced a converging wind near the surface of the Earth, and a contrary or divergent wind in the upper region of the air. But since the Earth does revolve on its axis, and the Sun therefore is not stationary, it must follow, that the place where the air is most rarefied will be found successively in every point of the parallel over which the

Sun moves in the course of a day. And as this place continually moves to the westward, the lower air must as constantly follow it. Hence we have the origio of the general N. E. and S. E. trade-winds, which no doubt would extend over the whole of the space between the tropics, were it not for the different temperatures of the continents and islands over which the Sun passes. For the surface of earth is more heated than that of the sea, by reason that the transparency of the water permits many of the rays of light to pass to its interior parts before they are stifled and lost. The air therefore, contiguous to the land, being more heated than that which rests upon the sea, will prevent the regularity of the effect. Thus, near the western coasts of Africa and America, the winds blow from the westward, to supply the constant rarefaction those heated lands produce.

The general N. E. and S. E. trade-winds, producing in the upper region of the air winds in the contrary directions, seem to be the cause of the westerly winds which are observed to prevail between the latitudes of 28° and 40° .

In accounting for the monsoons, or periodical trade-winds, it is necessary to mark the peculiar circumstances which obtain in the Indian Ocean, and which are not found in the Atlantic or Pacific Oceans. They seem to be these. That the ocean is bounded to the northward by shores, whose latitude does not exceed the limits of the general trade-wind, and that the general trade-wind falls on lee-shores to the westward.

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The Sun being twice in the year vertical in the equator, and never departing more than $23\frac{1}{2}^{\circ}$ from thence, causes the air in that climate to be hotter than at any other place on the ocean; and is the occasion of the trade-wind, as has already been shewn. Such a rarefied space must extend across the Indian Ocean, and produce a S. E. wind to the southward, and a N. E. wind to the northward of the equator, over which, in the upper regions of the air, the winds return in the contrary directions. This we accordingly see happens in the months of October, November, December, January, February, and March. But when the Sun declines to the northward, and heats the lands there, the air contiguous to those lands become rarefied, and the lower air has a tendency to move that way. This tendency increases as the Sun advances farther North, so that the whole body of the lower air to the northward of the equator moves towards the northern lands, notwithstanding the equatorial rarefaction, which must be supplied by the upper or returning current. It seems then that the body of the lower air in the northern part of the Indian Ocean is determined as to its course by the greater rarefaction: if the rarefaction at the surface of the land be greater than that at the equator, the wind blows to the North, and the contrary happens when the equatorial rarefaction is greatest. When the northerly trade-wind prevails, it blows out of the Arabian Gulf upon the coasts of Arabia, Aynan and Zanguebar, and is reflected into the straits of Mosambique.

Mofambique. And at the other feafon, the general foutherly wind feems to be reflected to the weftward by the fame caufe.

Thefe, or fome fuch like, are probably the caufes of the winds that prevail in the Indian feas. But the obfervations we are in poffeffion of are too few and too inaccurate for the purpofe of forming a theory.

On the fame principles it will not be difficult to account for the land and fea breezes. For, becaufe the land is heated in the day-time, the wind muft blow in fhore to fupply the place of the afcending rarefied air: and in the night the land cools, and condenses the air, occafioning the land breeze.

The circumftances that produce the variable winds are referable to thofe already noticed, but act fo differently in particular cafes and fituations, that it is fcarcely practicable to reduce them to any rule.

When feveral winds converge fwiftly to one point, the air afcends with great rapidity, and acquires a whirling motion, like that of water defcending in a funnel. And as the centrifugal force in this whirling motion of the water is often fufficient to counterpoife the lateral preffure, and to prevent its approaching the central part, it frequently happens, that a perforation is feen quite through the body of the fluid. In like manner, the centrifugal force of the air may become equal to the preffure of the atmofphere, and confequently leave a void fpace about the center of the motion. This phenomenon

is called a whirlwind, and sometimes produces fatal effects. For, partly by the expansion of the air included in houses or other buildings; and partly by the violence of the ascending current, it happens, that bodies near the center of the whirl are blown up into the vacuum, or carried aloft with great impetuosity in a spiral motion.

- M If one of these whirlwinds happen at sea, the pressure of the atmosphere being taken off that part of the surface over which the vacuum is formed, the water, on the principle of the Torricellian tube, will rise to the height of thirty-two or thirty-three feet before it will be in equilibrio with the external pressure. The ascending warm air being most probably charged with vapours, will suffer them to be condensed as it arrives in a colder region, and thus the course of the current will be marked by the dense and opaque vapor, and by the continual ascent a cloud will be formed above. These are the phenomena of water-spouts. At first a violent circular motion of the sea is observed for the space sometimes of twenty feet diameter; the sea rises afterwards by degrees into a tapering column of about thirty feet in height, at the same time that a cloud appears, from which a dark line or column descends. This column is met by another, which ascends somewhat like smoke in a chimney, from the lower or solid part of the spout. After this junction the cloud continually increases till the whirl ceases, and the appearance terminates.

C H A P. IV.

OF SOUND; AND OF MUSIC.

WHEN obtuse bodies move in elastic fluids, they condense that part towards which they move at the same time that the part they recede from is rarefied. This condensation or rarefaction must produce an undulatory or vibrating motion in the fluid. Thus, if a body by percussion or otherwise be put into a tremulous motion, every vibration of the body will excite a wave in the air, which will proceed in all directions so as to form a hollow sphere; and the quicker the vibrations of the body succeed each other, the less will be the distance between each successive wave. The sensation excited in the mind by means of these waves which enter the ear, and produce a like motion in a thin membrane, stretched obliquely across the auditory passage, is called sound. But the term is frequently used to imply not only the sensation excited in the mind, but likewise the affection of the air, or of the sonorous body by which that sensation is produced. Thus, we say, that a sound is in the air, or that a body sounds when struck, though the affection of the air or body is very different from the sensation.

That bodies move or tremble when they produce sound, requires no particular proof: it is evident in drums, bells, and other instruments, whose vibra-

tions being large and strong, are therefore more perceptible: and it is equally clear, that a similar vibration is excited in the air, because this vibration is communicated through the air to other bodies that are adapted to vibrate in the same manner: thus, bells, glasses, basons, and musical strings, will sound merely by the action propagated from other sounding bodies.

- Q It is established as well by mathematical reasoning from the nature of an elastic fluid, whose compression is as the weight, as from experiment, that all sounds whatever arrive at the ear in equal times
- R from sounding bodies equally distant. This common velocity is 1142 English feet in a second of time. The knowledge of the velocity of sound is of use for determining distances of ships, or other objects: for instance, suppose a ship fires a gun, the sound of which is heard 5 seconds after the flash is seen; then, 1142 multiplied by 5, gives the distance 5710 feet, or 1 English mile and 430 feet.

- S When the aerial waves meet with an obstacle which is hard, and of a regular surface, they are reflected; and consequently, an ear placed in the course of these reflected waves will perceive a sound similar to the original sound, but which will seem to proceed from a body situated in like position and distance behind the plane of reflection as the real sounding body is before it. This reflected sound is called an echo.

- T The waves of sound being thus reflexible, nearly the same in effect as the rays of light, may be deflected

deflected or magnified by much the same contrivances as are used in optics. From this property of reflection it happens, that sounds uttered in one focus of an elliptical cavity are heard much magnified in the other focus: instances of which are found in several domes and vaults, particularly the whispering gallery at St. Paul's Cathedral in London, where a whisper uttered at one side of the dome is reflected to the other, and may be very distinctly heard. On this principle also is constructed the speaking trumpet, which either is or ought to be a hollow parabolic conoid, having a perforation at the vertex, to which the mouth is to be applied in speaking, or the ear in hearing.

In addition to the advantages we enjoy from the perception of sound, when the sense of seeing cannot be employed, and in conveying our thoughts to each other by means of the associations formed between words and ideas, we receive great pleasure from the combination of sound known by the name of music.

If a body be struck, and the vibrations excited be all performed in equal times, the undulations produced in the air will be so likewise, and a simple and uniformly similar sound will be produced, except as to loudness or intensity; for, as the vibrations grow less strong, the sound decays. But if the vibrations excited be various and dissimilar, a like variety of dissimilar undulations will be produced in the air; and the sound must be harsh, as if several

sounds were heard together. The first of these sounds is a musical tone, and the latter a noise.

w This is confirmed by experience; for we find that those bodies which are the most uniform in their texture, and by consequence best adapted to vibrate simply and isochronally, always produce the most musical tones; as for example, masses of elastic metal, brass, cast-iron, and the like. And this tone is more strictly musical if the metal be so formed as to vibrate in the simplest manner possible. Thus, a hollow metallic vessel or bell, if it be well formed and not damaged in the tuning, will give but one uniform musical tone, or at least the tones produced will consist of one predominant or principal tone, and several others that have a perfect musical agreement with it. A wire of an uniform thickness, stretched over two hard bridges or fulcrums, will produce the same effect. Musical tones may be obtained by various means; but it will sufficiently answer our present purpose to attend only to the simplest method wherein strings or wires are made use of.

x Experience and reason have established the following positions respecting the vibrations of cords or strings.

y The forces or weights which are necessary to draw an extended chord $A \cdot B$ (fig. 133) out of its place to the distances $c \cdot e$, $c \cdot f$, $c \cdot g$, are directly proportional to those distances, provided the chord be not too much drawn aside.

There-

Therefore, since the forces with which the chord **z** returns to its first situation, when set at liberty, are always, in proportion to the space it has to pass through, the vibrations must all be performed in equal times.

If chords differ only in thickness, the times of **a** their vibrations will be directly as their diameters.

If chords differ only in tension, the times of **b** their vibrations will be inversely as the square roots of the weights by which they are stretched.

If chords differ only in length, the times of their **c** vibrations will be directly as their lengths.

That tone produced by a string that vibrates **d** quickly is termed acute or sharp, when compared with the tone of a string that vibrates slower; and the tone produced by the latter is called grave or flat, when compared with that of the former.

If two chords be struck, either at the same instant **e** or in intermediate succession, the coincidence of sound is pleasing or displeasing, accordingly as the two tones produced stand related to each other in gravity or acuteness: if they be so related as to afford pleasure, the coincidence is called a concord, but if not, it is termed a discord.

A set of tones which follow each other, and afford **f** pleasure, is called melody; a set of cotemporary tones which afford pleasure, is called harmony.

The more frequently the vibrations of two chords **g** coincide with each other the perfecter the concord will be; thus, two equal strings, equally stretched, will each give the same tone; the vibrations of the one

will coincide with those of the other, and the concord will be most perfect: again, two strings, differing only in length; the one being half the length of the other, will vibrate the one twice while the other vibrates once, the coincidence will be at every second vibration of the shorter string, and a concord will be produced, but less perfect; if the strings be in length as 2 to 3, the coincidence will be less frequent, namely, at the third vibration of the shorter string, and the concord will be still less perfect: and so forth.

- H By the help of these principles all stringed instruments are constructed; that series of musical tones being selected, which experience has shewn to be best adapted for the purposes of melody and
I harmony. The series is called the diatonic scale, and its properties, together with the names of the tones, may be seen in the following scheme:

Names.	Lengths.	Perfection.
Unison, or fundamental	1 : 1	Most perfect concord.
Second - -	10 : 9	Discord.
Third greater	5 : 4	Imperfect concord.
Fourth - - -	4 : 3	Imperfect concord.
Fifth - - -	3 : 2	Perfect concord.
Sixth greater -	5 : 3	Imperfect concord.
Seventh greater	15 : 8	Discord.
Octave - - -	2 : 1	Perfect concord.

- K The above is called the sharp series, in contradistinction to the flat series, or scale, wherein the third, sixth, and seventh are less or flat, being in
the

the ratios of 6 : 5, 8 : 5 and 9 : 5. There are likewise other intermediate tones used in practice, as the second less, and fourth greater, whose lengths are as 16 : 15, and 7 : 5. All these are found in the construction of instruments; that by their means the performer may place his fundamental, or principal note, on any of the tones at pleasure, and use the other tones which stand in the above relations to it; such being found sufficiently near for practice, though not so perfectly accurate as in the series the instrument is formed for.

The notation of music, and the relations of different scales to each other, together with the other particulars on which the rules for composition and accompaniment depend, require too copious an explanation to be admitted in this place.

C H A P. V.

A DESCRIPTION OF VARIOUS INSTRUMENTS, CONSISTING CHIEFLY OF SUCH AS DEPEND ON THE PROPERTIES OF THE AIR FOR THEIR EFFECTS.

M THE mercury in the Torricellian tube stands at the height of about thirty inches, by means of the pressure of the air, and in considering the phenomena of winds, we have seen that this pressure is not every where alike, nor always the same at any particular place. In consequence of this it happens, that the mercury in the Torricellian tube does not preserve the same invariable altitude: for, when the air at any place is dense, the mercury stands at a greater height than when it becomes lighter (32, B): thus the tube becomes an instrument to indicate the varying weight of the atmosphere, and when fixed in a proper frame with graduations to measure the altitude of the mercury, is known by the name of the barometer. The variations are between the altitudes of $27\frac{1}{2}$ and $30\frac{1}{2}$ inches.

N The heights of two barometers cannot be compared together with any exactness, unless they be both constructed in the best manner. The specific gravity of the included mercury ought to be accurately found; and it is necessary to boil it in the tube, for the purpose of effectually excluding the air and moisture from within. If the surface of the

mercury exposed to the air be larger than that in the tube, and this last be less than half an inch in diameter, the mercury will not rise to its full height. This difference ought to be known, and allowed for between different barometers.

The instrument, fig. 131, is used under the name of the marine barometer, it being useful at sea, where the common barometer is of little service, on account of the ship's motion, which causes the mercury to librate up and down in the tube. But as this barometer is subject to alteration, on account of heat and cold, as well as on account of change in the weight of the air; and the distinguishing the effects of each is attended with some little trouble, it is not much in use on shore

There are many contrivances for enlarging the divisions on the barometer, such as inclining the tube, and the like; but they are all subject to inconveniences, on account of friction, which the upright barometer is free from.

An instrument similar to the marine barometer was formerly made use of to indicate the varying temperature of the weather. For the marine barometer is also a thermometer, and its variations being thus occasioned by two causes, prevent its being applied to either purpose. The thermometer, or instrument used to exhibit degrees of heat and cold, is therefore constructed by the use of other fluids.

The property of expansion by heat not being peculiar to air, but common to all bodies, we are at liberty

liberty to choose any substance in nature for a thermometer. In this choice it is required, that the body made use of should be such, that its expansions may be the effect of heat alone, that they may be easily and correctly measured, and that the body may be capable of performing its office in temperatures very distant from each other. As the pressure of the atmosphere is not considerable enough to alter the dimensions of dense bodies in any sensible degree, it is plain that their mutations will indicate the effects of heat alone, and consequently they must be very proper for the matter of thermometers: but these mutations being very small in proportion to the whole bulk, solid bodies must be inconvenient for the purpose, on account of the great length required to make them perceptible: but in fluids, by means of proper vessels, it will be easy to render the least alteration visible; for if the neck or stem of any glass-vessel be very small in proportion to the contents of the bulb or bottle, the least expansion of the included liquor
 s will occasion a visible rise in the neck. Thus, *A B* (fig. 134) represents a glass-tube, whose end *A* is blown into a ball: this ball, and part of the tube, being filled with quicksilver, the least change of the bulk of the quicksilver, and consequently of the temperature of the circumambient air, or contiguous bodies, is shewn by a rise or fall of the surface in the tube; the quantity of which is indicated by the scale *a b*, affixed to the frame of the instrument.

Quick-

Quicksilver is the best fluid for thermometers, because it is not subject either to alter its expansibility, or to soil the tube, and gives besides a very extensive scale of divisions. The thermometer used in Britain is graduated according to the scale of the celebrated Fahrenheit. There are 180 divisions or degrees between the freezing and boiling water points; the freezing point being reckoned 32° above 0, or the commencement of the scale*. The degrees are counted both upwards and downwards from 0. A good thermometer must possess the following properties. The upper end must be hermetically sealed, and the empty space above the quicksilver must contain no air, or at most very little. This circumstance is ascertained by holding the instrument with the ball uppermost; in which situation the mercury will immediately run so as to fill the whole capacity of the tube. The scale must be well adjusted, and divided according to the capacity of the tube. To prove this, let the thermometer be taken from its scale, and laid in snow, or pounded ice, just beginning to melt: it should be covered nearly as high as the freezing point, or 32° is supposed to lie. When the mercury becomes stationary, mark the tube with the edge of a knife where it stands, or, if there be a mark ready made, as there commonly is, observe whether it accurately

* Reaumur's scale, principally used by the French, begins at the freezing point, and proceeds both ways from 0. From freezing to boiling water is 80 degrees.

agrees with the surface of the mercury; if it does, the freezing point is well settled. Wrap now several folds of linen rags or flannel round the tube of the thermometer nearly as high as the supposed boiling point; hold the ball of the thermometer in the ascending current of boiling rain-water about two or three inches below the surface; pour boiling water on the rags three or four times, waiting a few seconds between each time, and wait some seconds after the last time of pouring on water before the boiling point is marked on the tube, in order that the water may recover its full strength of boiling, which is considerably checked by pouring on the boiling water. This last experiment must be made when the barometer stands at 29.8 inches. The adjustment of the fixed points being thus ascertained, fasten the thermometer again to its scale, and agitate it so as to break or divide the thread of mercury in the tube. By variously inclining the instrument the separated portion of mercury may be made to rest in different parts of the tube, and its length observed on the scale. If its length in every part of the tube corresponds to the same number of degrees, the scale is well divided. This last object is by no means to be neglected: for it seldom happens that the diameters of thermometer-tubes are sufficiently regular to admit of a scale divided into equal parts. Such a scale will usually produce an error of upwards of a degree near the temperature of 120° , though the

the fixed points be ever so well settled; and in some instances the error may even amount to four or five degrees.

Thermometers with small bulbs, and tubes in proportion, are the most useful. For a large volume of mercury requires a considerable time to be either heated or cooled, and if it be immersed in any liquid, it will change the temperature of the liquid much more than a smaller instrument would have done, and consequently is less adapted to shew the temperature of the liquid at the time of its immersion. If the scale of a thermometer be of a dark colour, and the thread of mercury small, its station will be rendered more discernible by slipping a piece of white paper behind the tube.

The pressure of the atmosphere on the outside of a thermometer not being counteracted by the spring of any included air, is exerted in diminishing the size of the bulb, and sustains the mercury somewhat higher than it would stand, merely by reason of its temperature. This is proved by breaking off the sealed end of the tube; in consequence of which the mercury immediately falls. This quantity varies with the weight of the atmosphere, but the quantity of the variation can seldom amount to more than the tenth part of a degree. Thermometers with spherical bulbs are less acted on by the weight of the atmosphere than others.

If the bent tube CED (fig. 135) be filled with water, and the shorter leg EC immersed in the water contained in the vessel AB , the water will
all

all flow out at the aperture D , and the vessel will be emptied. For the pressure that supports the water in the leg CE is equal to the weight of the atmosphere, and is counteracted by the weight of the column EC , and the pressure that supports the water in the leg DE is the same weight, but counteracted by the column ED . And as ED is longer than EC , the pressure of the atmosphere on D will be less effectual than that on C ; consequently the whole mass of water in the tube will move towards the orifice D , receding from the greater pressure. This instrument is called a syphon, and is sometimes used to draw liquors out of casks that are so placed as not conveniently to be moved.

- x A very probable account of the cause of intermitting springs may be given on the principle of the syphon. For, let GFC (fig. 136) represent a cavity or receptacle in the bowels of a mountain, from the bottom of which C , proceeds the irregular cavity or syphon CED : then, if by springs or otherwise the receptacle begin to fill, the water will at the same time rise in the leg CE of the syphon till it has attained the horizontal level HH : when it will begin to flow out by means of the leg ED , and will continue to increase in the quantity discharged, as the water rises still higher, till at length the syphon will emit a full stream, and by that means empty the receptacle. At this period the stream will cease, till the receptacle being again filled, will again exhibit the same appearance. And these periodical returns of flood and cessation will be

be regular, if the filling of the reservoir be so; but the interval of the returns must depend on the dimensions of the apparatus, and the quantity of water furnished by the springs.

The action of that very useful instrument the *y* common pump, depends on the pressure of the atmosphere. It consists of a pipe *c d* (fig. 137) whose lower end *c* is immersed in water: at *b* is fixed a valve opening upwards, and in the superior part of the tube is worked a piston *A*, fitted very closely in the pipe by means of leather. In this also is a valve opening upwards. Now, if the part above *b* be filled with water, to render the whole air-tight, the piston *A* being thrust down to *b*, and afterwards raised, will leave a vacuum or void space between *b* and *A*, into which the air contained in the lower part of the pipe *c b*, will expand itself. The spring of this air being thus weakened by the expansion, will no longer counterpoise the effect of the pressure of the atmosphere, and the water will rise in the tube till the equilibrium is restored. By depressing the piston *A*, the valve *b* is suffered to close, and a part of the air between the valve and piston escapes through *A*. After a few strokes the whole of the included air is extracted, the water rises through the valve *b*, and is discharged by the piston *A*. This operation may be continued at pleasure. But if *z* the height *b c* be more than 34 feet, the water will not rise to the valve; for a column of fresh water of that length being equal to the weight of the atmosphere, it can be raised no higher by that weight.

weight. Thus it happens for the same reason that the mercury in the barometer never rises beyond a certain height; and if a pump, finished with the utmost exactness on the principle here described, be made to work in mercury, it will not raise it beyond that height.

A The fire-engine acts by means of the weight and elasticity of the air. For it is composed of two barrels, *E* and *D*, (fig. 138) in each of which a solid piston or plunger is worked by means of a double lever. These barrels communicate with the water by a pipe, not expressed in the figure: they also communicate with the strong cylinder or vessel *C*, by the pipes *L* and *T*. At *M* and *K* in the barrels are valves opening upwards, and at *L* and *T* are valves which open towards the cylinder. In the figure, the piston in *D* being raised, the water rushes in at *K*, while that in *E* being depressed, forces its contents into the cylinder through the valve *T*. At the next stroke the barrel *E* raises the water, while the contents of the barrel *D* are forced into the cylinder: and thus the alternate actions of raising and forcing may be continued at pleasure. Now, the water being forced into the cylinder, compresses the air contained within into a small space; and this air reacting on the water, drives it in a continual stream through the pipe *P O Q R*, which may be directed as necessity shall require.

B The great force of compressed air is shewn by many experiments, particularly in the performance of
of

of the wind-gun. Fig. 139, represents a section of this instrument. *A K* is the barrel, containing a ball at *K*. This barrel is contained within another larger tube *C D R E*, and in the intermediate cavity, the air is compressed and kept. *M N* is a cylindrical cavity in the stock or butt end of the piece, in which a piston works, for the purpose of forcing the air into the before-mentioned cavity. The air is prevented from returning by the shut or valve *P*, which is opened by the air, as it is forced in, but at other times, is kept shut by the spring of the included air. At *L* is placed another valve, pressed close by means of a spring on the orifice of the barrel, to prevent the air from escaping. A wire passing through a hole, rendered air-tight by wet and greasy leather, is affixed to this valve, and appears afterwards at *O*, in the form of a trigger. When the trigger is drawn back, the valve *L* opens, and the air rushing out, drives the ball with a force that seems not much less than if it were discharged from a musquet.

A variety of curious and pleasing fountains may be formed by the help of the properties of the air combined with hydrostatical principles. The following is one of the simplest. *A B C D* (fig. 140) is a copper vessel, near two thirds filled with water: at *M* is screwed in the tube *I G*, the junction being made air-tight by means of wet and greasy leather, and in the upper part of the tube is fixed a stop-cock *H*. The stop-cock being opened, a forcing syringe is screwed on at *I*, and a great quantity of

air injected, whence the air in the cavity $A B F E$ being very much condensed, presses on the surface of the included water. The stop-cock being then shut, the syringe is removed, and an adjutage screwed on in its place; through which, if the stop-cock be again opened, the water will spout forth with great violence.

- D Fig. 141, is a drawing of a very ingenious fountain, whose construction will be better understood from the section exhibited in fig. 142. $B C$ is an open dish, or vessel. $R S$ and $T U$ are reservoirs for water; each of which is divided into two by the partitions $V I$ and $X Y$. The tube $E F$ passes through without communicating with the upper reservoir, and serves to convey water from the basin $B C$ to the part $T X Y$ of the lower reservoir. The tube $G X$ forms a communication between the part $T X Y$ of the lower, and $R V I$ of the upper reservoir. The tube $I K$ forms a communication between the part $R V I$ of the upper, and $Y X U$ of the lower reservoir. And the tube $M L$ forms a communication between the part $Y X U$ of the lower, and $I V S$ of the upper reservoir. Lastly, there are openings at $O N P Q$, to fill or evacuate the reservoirs, and an adjutage pipe $D I$ communicating with the part $I V S$. The mode of action is this: water being poured into the upper reservoir by the openings O and N , the fountain is set upright, the openings being previously closed, and also the adjutage D . The basin $B C$ must then have water poured into it till it ceases to run down the pipe $E F$. In this state the fountain

fountain may be said to be charged. For the water that has passed down EF condenses the air in the part TXV , and also in the superior part $RV I$, by means of the tube of communication GH . In the same manner the water passes from the upper reservoir down the tube IK into the other lower part YXU , and condenses the air there as well as in the other upper part $V I S$, by means of the pipe of communication ML . The water in the upper part $V I S$ is therefore pressed by air condensed by the weight of the column IK , and also of the column EF , because IK is in effect pressed by this last. Open the adjutage D , and the water will issue out and rise (20 , B) to nearly the height of both the columns EF and IK together. The water in both those columns must descend, but as the tube EF is supplied by the falling jet that issues out of the chamber $V I S$, while the tube IK is supplied by the water from the chamber $RV I$, the fountain will continue to play till the upper chambers $V I S$ and $RV I$ have respectively emptied themselves into the lower chambers TXV and YXU .

In many mechanical engines, where the force E of an elastic fluid is required, the steam of boiling water is made use of, because it is easily obtained, is prodigiously elastic, and may be quickly deprived of its elasticity.

The first engine we have any account of, for raising water by the force of steam, was constructed about a century ago upon the principle of the figure, (fig. 143) where H represents a copper

boiler placed on a furnace. *z* is a strong iron vessel communicating with the boiler by means of a pipe at top, and with the main pipe *A B*, by means of a pipe *i* at bottom. *A B* is the main pipe immersed in the water at *B*. *D* and *c* are two fixed valves, both opening upwards, one being placed above, and the other below the pipe of communication *i*. Lastly, at *G* is a cock that serves occasionally to wet and cool the vessel *z*, by water from the main pipe, and *F* is a cock in the pipe of communication between the vessel *z* and the boiler.

- G* The engine is set to work, by filling the copper in part with water, and also the upper part of the main pipe above the valve *c*, the fire in the furnace being lighted at the same time. When the water boils strongly, the cock *F* is opened, the steam rushes into the vessel *z*, and expels the air from thence through the valve *c*. The vessel *z* thus filled, and violently heated by the steam, is suddenly cooled by the water which falls on it upon turning the cock *G*, the cock *F* being at the same time shut, to prevent any fresh accession of steam from the boiler. In consequence of this, the steam in *z* becoming condensed, leaves the cavity within almost intirely vacuum: the pressure of the atmosphere at *B*, therefore, forces the water through the valve *D* till the vessel *z* is nearly filled. The condensing cock *G* is then shut, and the steam cock *F* again opened; the steam rushing into *z*, expels the water through the valve *c*, as it before did

did the air. Thus *e* becomes again filled with hot steam, which is again cooled and condensed by the water from *g*, the supply of steam being cut off by shutting *f*, as in the former operation: the water consequently rushes through *d*, by the pressure of the atmosphere at *b*, and *e* is again filled. This water is forced up the main pipe through *c*, by opening *f* and shutting *g*, as before. It is easy to conceive, that by this alternate opening and shutting the cocks, water will be continually raised, as long as the boiler continues to supply the steam.

For the sake of perspicuity, the drawing is directed of the apparatus that serves to turn the two cocks at once, and of the contrivances for filling the copper to the proper quantity. The engines of this construction were usually made to work with two receivers or steam vessels, one to receive the steam, while the other was raising water by the condensation. This instrument has been since improved, by admitting the end of the condensing pipe *g* into the vessel *e*, by which means the steam is more suddenly and effectually condensed than by water on the outside of the vessel.

The advantages of this engine are, that it may be erected in almost any situation, requires but little room, and is subject to very little friction in its parts: its disadvantages are, that great part of the steam is condensed, and loses its force upon coming into contact with the water in the vessel *e*, and that the heat, and elasticity of the steam must

be increased in proportion to the height the water is required to be raised to. On both these accounts a large fire is required, and the copper must be very strong, when the height is considerable, otherwise there is danger of its bursting. The following engine is much to be preferred when the work to be done is heavy, and is less chargeable in fuel, because it acts by means of steam whose density is not much greater than that of the common air.

K In fig. 144, **H** represents the copper boiler on its furnace. **E** is a cylindrical vessel of iron, in which the piston **o o** moves up and down; the edges of the piston being armed with oakum and greafe, render the whole cavity between the piston and the bottom of the cylinder air-tight. **F** is a cock to admit steam into the cylinder from the boiler. **I K** is a lever, attached to the piston at **I**, and at **K** to the piston of a pump which works on that side. **P Q** is a solid piston moving in the pipe **R M**, and loaded with a heavy weight at **P**. **A B C** is the main pipe that receives the water forced from **R M** through a valve **c** opening outwards. **N** is an air-vessel communicating with the main pipe. **D** is a valve opening upwards, and at **M** is the water to be raised.

L In the drawing, the engine is represented in the position it has at the end of a forcing stroke, which is likewise its position when at rest. Suppose the main pipe **A B C** to be filled with water, and the water in the copper **H** to boil strongly.

The

The cock *F* being then opened, the steam rushes into the cylinder, and being much lighter than the air, rises to the top, and expels the air through a valve in the bottom of the cylinder. This being accomplished, *F* is shut, and the cock *G* communicating with the main pipe is opened, which immediately condenses the steam, by violently spouting cold water against the bottom of the piston. A vacuum being thus obtained, the pressure of the atmosphere forces the piston down to the bottom of the cylinder; the lever *IK* is moved of course, the piston *PQ* with its weight is raised, and the water ascends in the pipe *MR* upon the principle of the common pump. The cock *G* being now shut, and *F* opened, the steam enters the cylinder, and counteracts the pressure of the atmosphere on the piston *oo*. In consequence of this, the weight *P* prevails, and drives down the piston *RQ*, forcing the water through the valve *c* into the main pipe and its air vessel. The use of the air vessel is to prevent the main pipe from bursting by the sudden entrance of the water; for the air at *N* being elastic, gives way to the stroke, and its reaction during the time of elevating the piston *PQ* continues the motion of the water, so that its velocity is no more than half what it would have been if it had been impelled by starts, and rested during the raising of the piston. By opening the cock *G* and shutting *F*, the steam is again condensed, the pressure of the atmosphere again prevails, and thus the work may be continued at pleasure.

- M In this drawing likewise, the mechanism is omitted, that serves to open and shut the cocks. This office is performed by a beam and ropes attached to the lever *k*, so that the attendance required is very little more than is necessary to supply the boiler with water, and to prevent the fire from going out.
- N The chief advantage of this engine beyond the former is, that the water may be forced to any height without increasing the force of the steam, which never need be much greater than that of the atmosphere; and therefore the boiler is very little endangered. The maximum of its power depends upon the area of the piston *o o*; for the larger the area, the greater the column of the atmosphere that presses it, and consequently the heavier the weight *p* or counterpoise may be. If *o o* the piston be 36 inches in diameter, it will be pressed by a column of the atmosphere equal in weight to a column of mercury of that diameter, and 30 inches in height; that is to say, almost 7 ton.
- O But, notwithstanding the great skill and contrivance displayed in this engine, it is at present almost entirely superseded by one of a much better construction, invented and perfected by Messrs. Watt and Boulton, of Birmingham. In their engine, instead of the piston *o o* being depressed by means of the weight of the atmosphere, the steam is thrown upon it; the upper part of the cylinder *e* being closed, and the rod *L* of the piston which is smooth and polished, being admitted through a perforation, which

which is wadded so as to be air-tight. The ascent of the piston is obtained by letting the steam out of the cylinder into a vessel at a considerable distance, where it meets with, and is condensed by a jet of cold water; while a vacuum is constantly maintained in the lower part of the cylinder by the action of the pump that carries off the injection water. The force of steam employed in this engine is usually equal to one atmosphere and a quarter, and the whole apparatus is regularly worked by the principal lever *IK*. The advantages of this construction are, that by increasing the force of the steam the power of the engine may be increased, without enlarging the diameter of the cylinder; and a less expence of steam is required on account of the condensation being performed at a distance from the cylinder, which is not therefore cooled by the injection of the cold water. This last circumstance renders the engine capable of making a greater number of strokes in a minute with a much less expence of fuel than the old engine. In some of the latest improved engines the action of the steam is rendered equal on the lever, by adapting the figure of the arch at its extremity, so that the lever is in effect rendered longer, towards the end of the stroke, where the power of the steam is weaker.

The elasticity of the air affords a method of determining the depth of the sea in places where a line cannot be used. Fig. 145, is a machine for this purpose. *A* represents a large ball of fir
or

or other light wood, varnished over, to preserve it from the effects of the water; B is a hollow glass vessel, whose contents in sea water are exactly known; suppose, for instance, two pounds: its neck c terminates in a small orifice, and is bent downwards, to prevent the escape of the included air, when it is immersed in water. At E is a spring-hook, which, if at liberty, would stand in the position e, but is pressed through a slit in the stem at the bottom, and kept to its place by hooking on the weight D. The whole instrument thus prepared is suffered to sink in the water. And the consequence is, that as it sinks, the pressure of the water continually increasing, forces its way into the vessel, and condenses the air contained within; but when it arrives at the bottom, the weight D striking first, is stopped, while the rest of the apparatus proceeds a little onwards, by reason of its acquired velocity. The hook E being thus disengaged from the weight, flies back, and leaves it intirely, so that the ball A is at liberty to rise again to the surface. From the quantity of water contained in B at its emergence, it is easy to determine the depth it has descended to. For, since the density of air is as the compressing weight, the bulk of the same quantity of air under different pressures, must be inversely as the weight. And experiment shews, that the mean weight of the atmosphere is equal to about 32 feet of sea-water: therefore, at the depth of 32 feet, the air included in the vessel c will sustain the pressure of

two atmospheres, and consequently will be condensed into half its former space; at 64 feet depth it will sustain the pressure of three atmospheres, and be condensed into one third of its first space, and so forth. Suppose, for example, an empty ball, as above described, capable of holding two pounds troy of sea-water, were to descend to an unknown depth in the sea, and at its return was found to contain 1 lb. 11 oz. 18 dwts. of water, it is required to find the depth? Then, as the bulk the air was compressed into, when at the bottom of the sea, which is expressed by 2 dwts. Is to the bulk of the air before immersion, expressed by 2 lb. So is the weight of the atmosphere, by which the air was compressed before immersion, which is expressed by 32 feet of water, To the weight by which the air was compressed when at the bottom of the sea, 3840 feet. From which deduct 32 feet for the pressure of the atmosphere, and the remainder, 3808 feet, indicates the depth of the sea.

This method is subject to two objections. The first is, that probably the specific gravity of the sea may be different at different depths, and consequently the pressures may not be as the depths: the other is, that air in very great condensations does not strictly follow the ratio of the pressure, but resists in a greater degree. A careful series of experiments may however indicate the allowances necessary to be made on both accounts, and in small depths the instrument is sufficiently accurate

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on the principle already laid down. If this instrument were to be applied to measure considerable depths, the temperature of the submarine regions would require to be found and allowed for.

R It is a well-known fact, that an empty vessel, that is to say, a vessel containing air, immersed in water with the mouth downwards, will not become filled, because the spring of the air will prevent the water from entering, as may be easily seen by the help of a wine-glass. The diving-bell is constructed on this principle. It consists of a large vessel, or kind of cask, so loaded with lead as to sink when empty, with the mouth downwards. In the top is fixed a cock to let out the air, and a strong pane of glass to afford light to the divers, who sit on a circular bench in the inside. This machine is lowered into the water about twelve feet at a time, and at each pause air is sent down in smaller bells to the divers, and by them received into the cavity of the great bell, for the purpose of expelling the water that enters as the pressure condenses the included air. After it has arrived at the bottom of the sea, the operators continue by the same means to replenish the air which becomes foul by breathing, suffering the impure air to escape by the cock in the upper part, as they receive fresh air by the barrels or small bells; so that by this contrivance they can remain under water as long as they please.

s The air-balloon is of two kinds; the one intended to contain heated air, and the other inflammable

flammable air. Hot air occupies more space when colder (54, G), and inflammable air is much lighter at a given temperature than the common air of the atmosphere. From this it follows, that any mass of either heated or inflammable air, if at liberty, will ascend in the atmosphere with a force of buoyancy equal to the difference between its own weight and the weight of an equal bulk of common air (9, B). If the heated or the inflammable air be included in a bag, and the weight of the bag be less than the difference just mentioned, the bag will be carried upwards, though with a less degree of force, namely, with a force equal to the difference lessened by the weight of the bag. This is commonly called an air-balloon; which, though its figure is not essential to its property of ascending, we will suppose to be a globe. If the magnitude of a balloon be increased, its power of ascension, or the difference between the weight of the included air and an equal bulk of common air will be augmented in the same proportion; that is to say, in proportion to the cube of its diameter. But the weight of the covering or bag will not be increased in so great a proportion. For its thickness being supposed the same, it is as the surface it covers, or only as the square of the diameter. This circumstance is the cause why balloons cannot be made to ascend, if under a given magnitude, with cloth or materials of the same thickness.

- v Fig. 146, represents the balloon first invented. It consists of an immense bag of canvas, or other cloth, painted with a composition that may lessen its susceptibility to take fire. A net covers the upper part of its surface, from which proceed ropes that sustain a gallery to carry the adventurers and fuel. The lower part is affixed to the gallery, and open to receive the streams of heated and rarefied air, produced by means of fire maintained in an iron grate, suspended in the middle of the orifice. The first inflation of the balloon is effected by means of a fire made in a proper apparatus on the ground, and the attached grate serves only to maintain the requisite degree of rarefaction, by furnishing a supply of heated air in the room of that which is gradually condensed by cooling. It is ascertained from experiment, that the rarity of the air in these machines depends solely on its heat and its property of cooling slowly; and it is likewise established with a considerable degree of certainty, that the weight of the included air is at a medium, about two thirds of the weight of an equal bulk of the air of the atmosphere. This balloon is raised or lowered while in the atmosphere, by increasing or diminishing the fire.
- v Small balloons of thin paper, raised on this principle by the flame of a sponge, or ball of cotton dipped in spirits of wine, have been exhibited in every part of Europe.
- w The inflammable air-balloon, fig. 147, is preferable to the other, in the present early state of
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our knowledge. It is usually formed of thin silk varnished over. When filled with inflammable air, its tube of communication *A* is usually closed, so that the air is prevented from escaping. The adventurers are placed in a car or small vessel *B*, attached to the balloon by strings, proceeding from a net that covers its upper part. They carry bags of sand with them to serve as ballast, and the end of the tube of communication, as well as a string that by pulling may open a valve in the top of the balloon, are continued down into the car. By those means they have, for a limited time, the power of ascending or descending at pleasure. For the power of ascension is increased by emptying one or more sand-bags, or diminished by suffering the inflammable air to escape either by the tube or through the valve. It may be observed, that the inflammable air, on account of its greater lightness, will not descend through the tube of communication, unless either by its own expansion from heat, or by the diminished pressure of the atmosphere at great heights, it is made to escape while the balloon is fully inflated; but it will issue from the upper valve, when open, in all circumstances whatever.

The inflammable air produced in the large way, *x* by the effusion of diluted vitriolic acid, on iron shavings or turnings, is rather less than one fifth of the weight of an equal bulk of atmospherical air. It is estimated that a cubic inch of iron gives a cubic foot of inflammable air, and the strong
vitriolic

vitriolic acid, sold in London, requires to be diluted by five times its bulk of water, for this experiment.

Y To give at pleasure a progressive motion to air-balloons, in any required direction, is a problem of great importance in this newly discovered art of penetrating into the superior regions of the atmosphere. Many wild and absurd schemes for this purpose have been offered to the consideration of the public; and some that have been carried into effect have served only to evince the ignorance or the artful quackery of their projectors. Little however of real value has been yet done towards accomplishing this purpose. The grand difficulty of the attempt consists in the large surface of resistance exposed to the surrounding fluid, which has hitherto been such, that the quantity of air required to be displaced is so great, that the strength of the voyagers cannot displace it with any considerable velocity; that is to say, when they have given a small degree of velocity to the machine, the resistance of the air becomes such, that their whole strength will be employed in over-

Z coming it, instead of adding to the velocity. The principal object therefore must be, to construct the balloon of such a figure as that it may move through the air without displacing any considerable quantity of it. As to the application of the strength, it may be done by a variety of methods. It is required that it should be exerted on the air in the opposite direction to that intended to be produced

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in the balloon, and as no mechanism can bestow or create strength (1. 73, &c) the simplest machine will be the best, because the loss by friction will then be least.

The uses to which machines of this kind may be applied are numerous, and will easily occur to any ingenious person. It will probably be long before the experiment will be performed in a sufficiently cheap way to admit of its being applied to the ordinary purposes of travellers. Its use on extraordinary occasions, for the conveyance of intelligence in military operations; for penetrating into places inaccessible by other means; or, for making philosophical observations on the superior regions of the atmosphere, are sufficiently obvious. We cannot, however, boast of any addition having been made to the stock of atmospherical knowledge, though very many aerial voyages have been performed. The probable causes of this are, that the balloons have seldom ascended above two miles high; that the novelty and grandeur of the scene beheld from a balloon has prevented a strict attention to the phenomena that may have presented themselves; and more especially, that most of the experiments were performed by ignorant and mercenary imitators, who have been much more desirous of taking the advantage of the surprize and credulity of the vulgar, than of making valuable observations, or relating them with fidelity.

The invention of the heated air balloon is the undoubted right of the brothers, Messrs. Stephen

and John Mongolfier, who made the first experiment at Avignon in November, 1782. The first balloon raised in the atmosphere by means of inflammable air, was constructed by public subscription, opened by M. Faujas St. Fond at Paris. Messrs. Roberts were appointed to construct the machine, and M. Charles to superintend the work. It was launched from the Champ de Mars August 27, 1783. The first human being that ascended into the air by means of an air-balloon was M. Pilatre de Rozier. He was afterwards accompanied by M. Gironde de Vilette, and afterwards by the Marquis d'Arlandes. The balloon used in these experiments rose by heated air, and was constructed by John Mongolfier at Paris. It was prevented from escaping by ropes. The first aerial voyage was performed with the same balloon by M. Pilatre de Rozier and the Marquis d'Arlandes, who passed over the city of Paris November 21, 1783. The first aerial voyage with a balloon filled with inflammable air was made by Messrs. Charles and Robert from Paris December 1, 1783. They were carried about twenty-seven miles in one hour and three quarters. The great rarity of inflammable air was first ascertained (in 1766) by Mr. Cavendish, and the idea of its application to the purpose of floating a bag in the atmosphere was explained by Dr. Black in his lectures next following that period. Several philosophers made attempts to carry this into effect previous to June 1782, and succeeded so far as to inflate soap-bubbles with inflam-

inflammable air, which rapidly ascended to the ceiling of the room. But it is to the philosophic spirit and liberality of our neighbours the French that we are indebted for this experiment being completely performed in the large way, without whose encouragement it might probably have long remained nothing more than a happy thought*.

On the 14th of June, 1785, the intrepid and ingenious Pilatre de Rozier fell a victim to the new art in which he was the first adventurer. He attempted to cross the British channel in company with a gentleman, whose name was Romain. His balloon consisted of two parts: the upper contained inflammable air, and the lower part was a balloon for heated air. By this ingenious addition it was expected, that a power of ascending or descending at pleasure, without loss either of ballast or of inflammable air, would have been obtained. When the unfortunate travellers were at the estimate height of about six thousand toises, the upper balloon took fire near the top, and burst. The apparatus immediately fell to the ground. Pilatre de Rozier first came to the earth: no signs of life were perceived in him, but his companion is said to have uttered an exclamation before he expired.

This much lamented event is supposed to have arisen either from the electricity of the clouds setting fire to the stream of inflammable air that

* For a further account of this subject, the English reader may have recourse to Cavallo's History and Practice of Aero-station.

issued from the upper valve, or from the inflammable air that escaped, forming a train of communication between the upper balloon and the fire beneath, which in its ascent was continually brought into the place before occupied by the balloon. This last opinion is rendered most probable, from the agitation and apparent distress observed in the travellers a short time before the catastrophe. They had prudently lowered the stove before Pilatre de Rozier opened the upper valve. The efflux of inflammable air occasioned by this last manœuvre was probably the immediate cause of their destruction*.

C H A P. VI.

OF THE AIR-PUMP AND ITS USES.

B THE air-pump is one of the most useful of all philosophical instruments, whose actions depend on the properties of the air. By the help of this machine, all that has been shewn concerning the weight and elasticity of the air, is demonstrated in the most simple and elegant manner. Its construction is as follows: *EFGH* (fig. 148) is a square table of wood, *AA* are two strong barrels or tubes of brass, firmly retained in their position by the piece *TT*, which is pressed on them by screws *OO*, fixed on the tops of the brass pillars *NN*. These barrels communicate with a cavity in the lower part

* See the *Courier de l'Europe* for July 1, 1785.

D. At the bottom within each barrel is fixed a valve, opening upwards, and in each a piston works, having a valve likewise opening upwards. The pistons are moved by a cog-wheel in the piece TT , turned by the handle B , and whose teeth catch in the racks of the pistons CC . PQR is a circular brass-plate, having near its center the orifice κ of a concealed pipe, that communicates with the cavity; in the piece D at v is a screw that closes the orifice of another pipe, for the purpose of admitting the external air when required. LM is a glass-receiver, out of which the air is to be exhausted. It is placed on the plate PQR , first covered with a wet sheep-skin, or smeared with wax, to prevent the air from insinuating under the edge of the glass.

When the handle B is turned, one of the pistons c is raised, and the other depressed; a void space is consequently left between the raised piston and the lower valve in the correspondent barrel: the air contained in the receiver LM , communicating with the barrel by the orifice κ , immediately raises the lower valve by its spring, and expands into the void space; and thus a part of the air in the receiver is extracted. The handle then being turned the contrary way, raises the other piston, and performs the same act in its correspondent barrel; while, in the mean time, the first mentioned piston being depressed, the air, by its spring, closes the lower valve, and, raising the valve in the piston, makes its escape. The motion of the handle being again reversed, the first barrel again

exhausts while the second discharges the air in its turn: and thus, during the time the pump is worked, one barrel exhausts the air from the receiver, while the other discharges it through the valve in its piston.

D Hence it is evident, that the vacuum in the receiver of the air-pump can never be perfect; that is, the air can never be entirely exhausted: for it is the spring of the air in the receiver that raises the valve, and forces air into the barrel, and the barrel at each exsuction can only take away a certain part of the remaining air, which is in proportion to the quantity before the stroke, as the capacity of the barrel is to that of the barrel and receiver added into one sum.

E This, however, is an imperfection that is seldom, if ever, of any consequence in practice, because all air-pumps, at a certain period of the exhaustion, cease to act, on account of their imperfect construction. For the valves usually consist of a piece of oiled bladder tied over a hole, so that the air is at liberty to pass by lifting up the bladder, but cannot return again, and there will unavoidably be a small space left between the lower valve and the piston when down. Now, it will happen, when the air in the receiver is very rare, that its spring will not be strong enough to overcome the adhesion of the bladder forming the lower valve, which, consequently, will remain shut, and the exhaustion cannot proceed. Or, before this period, it may happen, that the air between the valves when the
piston

piston is up may be so small as to lie in the space between the two valves when the piston is down, without being sufficiently condensed for its spring to overcome the adhesion of the bladder forming the upper valve, and the weight of the atmosphere that presses it: in this case the upper valve will remain shut, and the exhaustion cannot proceed. In the best air-pumps these imperfections are in a great degree removed. For the adhesion of the bladders is much diminished, and the action of the air upon them increased, by substituting a number of large holes of passage, instead of one smaller. By causing the rod of the piston to pass through a collar of leathers, screwed to the upper part of the barrel, and placing another valve for the passage of the extruded air, the pressure of the atmosphere is prevented from acting on the piston, so that the whole spring of the air between the piston and lower valve is exerted in overcoming the resistance afforded by the valve of the piston. There are also contrivances for opening a communication between the receiver and the barrel, without depending on the spring of the air. One of the best of these consists in an additional piece that lifts the lower valve when a lever is pressed with the foot: the lever communicates with the interior piece by means of a rod that passes through a collar of leathers at the lower end of the barrel*. The best sort of air-pumps are usually made with a single barrel.

* This is the invention of one ——— Haas, a workman in London, who has taken out a patent for it.

In measuring the exhaustion there are two methods of proceeding. The one shews the density of the air left in the receiver, without regarding such vapours as may assume an elastic form in the vacuum: the other exhibits the spring of the elastic fluid in the receiver, without shewing whether it be permanently elastic air. The quantity of air is shewn by an instrument called the pear-gage. It consists of a glass-vessel in the form of a pear, with graduations near its upper end, that denote certain known parts of its bulk. This is included in the receiver, together with a vessel of mercury, into which its mouth may be occasionally plunged. When the exhaustion is made, the pear-gage is plunged into the mercury, and the external air admitted into the receiver. The mercury rises in the gage, and occupies the whole of its cavity, except a space at top, possessed by a bubble of air, whose magnitude is known from the graduations, and is in proportion to the whole contents of the gage, as the quantity of air in the exhausted receiver is to an equal volume of the common atmospheric air.

- o This gage would be accurate for all purposes, if it were not that moist fluid or moist substances assume an elastic form when the pressure of the atmosphere is removed. For this reason it seldom indicates the elasticity or actual pressure of the fluid remaining in the receiver. The barometer gage is used for this purpose. If a barometer be included beneath a receiver, the mercury will stand at the same height

as in the open air; but when the receiver begins to be exhausted, the mercury will descend, and rest at a height, which is in proportion to its former height as the spring of the remaining air is to its original spring before the exhaustion. It is usual to say, the air is as many times rarer than the atmosphere, as the column it sustains is less than the height the mercury stands at in a detached barometer. On account of the inconvenience of including a barometer in a receiver, a tube of six or eight inches length is filled with mercury, and inverted in the same manner as the barometer. This being included, answers the same purpose, with no other difference than that the mercury does not begin to descend till about three-fourths of the air is exhausted. It is called the short barometer gage. Others place a tube, of a greater length than the barometer, with its lower end in a vessel of mercury, while its upper end communicates with the receiver. Here the mercury rises as the exhaustion proceeds, and the pressure of the remaining air is shewn by the difference between its height and that of the barometer. This is called the long barometer gage.

These gages are not often constructed so as to answer the purpose of shewing the degree of exhaustion to a great degree. For the mercury, though at first boiled, to clear it of the air and moisture that adhere to it, and render it sensibly lighter, gradually becomes again contaminated by exposure to the air in the basin of either gage. They cannot therefore with strictness be compared with

with a good barometer. in which this does not happen. If the tubes of the gages be less than half an inch in diameter, the mercury will be sensibly repelled downwards, so as to require a correction for the long gage when compared with a barometer, whose tube is of a different bore, and to render the short gage useless in great exhaustions. Thus, for example, if the short gage have a tube of one-tenth of an inch in diameter, the mercury will fall to the level of the basin when the exhaustion is 150 times, and will stand below the level for all greater degrees of rarefaction. These difficulties may all be removed, by making the short gage in the form of an inverted syphon, with one leg open, and the other hermetically sealed. It must be confessed, however, that it is not easy to boil the mercury in these; and the method of doing it with success cannot, with sufficient conciseness, be described here.

i Few air-pumps exhaust to so great a degree as one thousand times by the barometer gage; but the pear-gage in some circumstances will indicate an exhaustion of many thousand times.

x Several of the uses of the air-pump have already been mentioned. The weight of the air is shewn by exhausting it out of a bottle (30, x) and its pressure is proved to be the cause of the ascent of the mercury in the barometer, because in the vacuum it is no longer sustained. It will be proper to subjoin a few more instances.

If

If a square bottle, in whose neck is fixed a valve, ^L opening outwards, be placed under the receiver, and the air exhausted, the bottle will be crushed to pieces by the weight of the atmosphere when the air is permitted to return into the receiver. For the air is prevented from entering the bottle by the valve, which, before the exhaustion, sustained the pressure of the atmosphere on its external surface, by means of the spring of the included air acting equally on the internal surface; but in this experiment, being deprived of its internal air, it is incapable of bearing the weight of the atmosphere, which presses it on all sides. If the bottle were round instead of square it would sustain the pressure, notwithstanding the exhaustion, by reason of its arched figure, that would prevent its giving way inwards.

The quantity of this pressure on a given surface ^M is equal to the weight of a column of mercury, whose base is the given surface, and whose height is the height of the mercury in the barometer. (32, B) To exemplify and prove this by the air-pump, it is usual to inclose in the receiver two brass hemispheres, as A and B (fig. 149), that shut together like a box, and at the place of shutting are lined with wetted leather. The air being exhausted from the receiver, escapes likewise from the cavity of the hemispheres, and when it is permitted again to enter the receiver, the hemispheres are so closely pressed together, that the air cannot enter at the place of junction: they adhere together

ther therefore, with a force equal to the pressure of the atmosphere, which is greater or less in proportion to the area of the circle at the place of junction. Thus, if the diameter of the circle where the hemispheres are joined be four inches, the force required to separate them must exceed 230 lb. troy.

- n Since bodies immersed in fluids lose parts of their weights, which are equal to the weights of masses of the fluids respectively equal in bulk to the bodies themselves (8, 2, A), it follows that bodies of different specific gravities, which are in equilibrio in the air, will not remain so in vacuo. For in vacuo each body will re-acquire the weight they lose while in the air, and the body, whose bulk is greatest, will acquire the greatest weight. Thus, if a piece of cork be in equilibrio with a piece of lead, when weighed by fine scales in the air, the cork will preponderate in vacuo; the removal of the air adding proportionally more to its weight, as its bulk exceeds that of the lead.
- o The spring of the air may likewise be shewn in a variety of manners by the assistance of the air-pump. Suppose a small tube to be inserted through the cork of a bottle, half full of mercury, so that the communication between the air included in the upper part of the bottle and the external air shall be entirely cut off, the end of the tube being immersed in the mercury. Let this apparatus be placed under the receiver, and the air exhausted. The spring of the included air then pressing on the surface

surface of the mercury, will force it into the tube, and sustain it at the same height nearly as it stands in the barometer; for the spring of the air is equal to its weight (1. 22, R), and consequently produces an equal effect: but on account of the imperfection of the vacuum, and the expansion of the air in the bottle, by which its spring is weakened, the mercury does not rise exactly as high as it does in the barometer.

If a half blown bladder be placed in the receiver, P the included air will expand as the exhaustion proceeds, and will blow it up even to bursting. And if this bladder be inclosed in a box, whose cover is loaded with weights somewhat less than equal to that of the atmosphere, the expansion will raise the cover and sustain the weights. Thus, if the bladder be inclosed in a box of 6 inches diameter, it will raise the cover, though loaded with upwards of 500 lb. troy (32, B).

The spring of the air included in the larger pores Q or vessels of bodies, is the foundation of a number of pleasing and instructive experiments. Thus it is found, that wood is specifically lighter than water, only by reason of the spring of the air included in its vessels, that prevents the water from entering: for when this air is extracted, and the water, by the admission of the external air into the receiver, is impelled into the vessels of the wood, it is always found to sink to the bottom.

The refractive power of the air is also shewn by R the air-pump. For if the air be exhausted out of a prismatic

a prismatic glass-vessel, the rays of light will not pass straight through its sides, but, in passing through the vacuum, will be deflected according to the established laws of optics. The proportions of the sines of the angles of incidence and refraction, out of the vacuum into the air, are by this means found to be as 100036 to 100000, which is nearly the same ratio as is deduced from the refractions of the heavenly bodies.

s It is likewise proved by the air-pump, that the air is the medium of sound. A bell or small alarm clock, being rung in the exhausted receiver, gives no sound, but if the air be admitted, the sound gradually becomes louder and louder, till the air in the receiver be of the same density with that of the atmosphere, at which time the sound is no otherwise weakened than on account of the receiver that covers the bell.

t The resistance of the air is exhibited in a striking manner by the help of the air-pump; for, if a guinea and a feather be let fall together from the top of a tall exhausted receiver, they both arrive at the bottom at the same instant.

u Among the very numerous instances of the usefulness of this instrument, we shall mention but two more; namely, the discovery of the absolute necessity of air for the preservation of life in most animals, and for the production and continuance of flame. Most animals, when included in the exhausted receiver, are observed to die in about five minutes, though the time is various in different species;

species; and they mostly recover again, if the air be again admitted without being withheld too long. A lighted candle placed under the receiver, is extinguished at the beginning of the rarefaction, and the smoke hovers about the top of the receiver; but when the air is still more rarefied, it becomes specifically heavier, and subsides to the bottom.

B O O K III.

S E C T. I.

Of Chemistry.

C H A P. I.

CONCERNING HEAT.

- v EVERY change that can take place in bodies is effected by means of motion. The business of natural philosophy is to investigate the causes of the several motions, and the laws they follow. In many instances these motions come under the inspection of our senses, but for the most part they are performed among the minute parts of bodies, and are only known by the effects they produce. The foregoing part of this work has been chiefly confined to the explanation of the former kind of motions, which may be denoted by the general term mechanics. The latter, namely, the effects produced by motions among bodies too minute to affect the senses individually, are the object of a science called chemistry.
- v Heat is one of the most important and general causes of change in bodies. This term is commonly

monly used to denote as well the sensation caused by an increase of temperature in the human body as the state in which inanimate bodies are when their temperature is increased. In the following pages, however, it will not be necessary to attend to the sensation. The word temperature will be used to denote the state of a given solid, fluid, or vaporous body, with respect to heat; and the word heat will be used to denote the cause of that state.

A body is said to be hot or cold accordingly as *w* its temperature is above or below a given standard. The vulgar make use of the temperature of the human body as a standard for this purpose. But this is by no means accurate enough for philosophical purposes, because the sensations of no two persons agree, nor even those of the same person at different times.

The dimensions of a body are always increased *x* with the temperature, so long as the body retains the state of solidity, fluidity, or vapour, it happens to possess, and has suffered no change either in the combination or quantity of its chemical principles. This is the chief, and, perhaps, the only general criterion by which the changes of temperature can be appreciated.

Bodies in contact, or that communicate with each *y* other, will all acquire one and the same temperature, after a certain length of time, however different their respective original temperatures may have been.

There are two opinions concerning heat. Accord- *z*
ing to one opinion, heat consists in a vibratory mo-

tion of the parts of bodies among each other, whose greater or less intensity occasions the increase or diminution of temperature: according to the other opinion, heat is a subtile fluid that easily pervades the pores of all bodies, causing them to expand by means of its elasticity, or otherwise. Each of these opinions is attended with its peculiar difficulties. The phenomena of heat may be accounted for by either of them, provided certain suppositions be allowed to each respectively; but the want of proof of the truth of such suppositions renders it very difficult, if not impossible, to decide, as yet, whether heat consists merely in motion or in some peculiar matter.

- A The word quantity applied to heat will therefore denote either motion or matter, according to the opinion made use of, and may be used indefinitely without determining which.
- B Whatever heat may be, it is certainly lawful to affirm, that when the temperatures are the same, the quantities of heat are equal in equal bodies of the same kind; thus, a pound of gold contains an equal quantity of heat with another pound of gold at the same temperature, a pound of water contains an equal quantity of heat with another pound of water at the same temperature, &c. Hence it follows, that the quantity of heat in two pounds of a given substance is twice as much as is contained
- c in one pound at the same temperature; and universally in homogenous bodies of the same kind, the quantities of heat will be as the masses, provided the temperatures be the same.

If two bodies that differ only in temperature be brought into contact, they will (113, γ) acquire a common temperature, and the quantity of heat in each will be equal (114, β). It is therefore seen, that the hotter body has imparted half its surplus of heat to the other; and consequently the quantity of heat in one of the two bodies will be an arithmetical mean between the quantities originally contained in them.

If two bodies of the same kind that differ in magnitude and temperature be brought into contact, they will (113, γ) acquire a common temperature, and the quantity of heat in each will be (114, c) in proportion to the masses: that is to say, the quantity of heat which caused one of the two bodies to be hotter than the other will be divided between them in proportion to their masses.

The quantities of heat required to be imparted to, or subducted from, bodies of the same kind, in order to bring their temperature to any given standard, will consequently be as their masses.

On these considerations it is that the thermometer is presumed to acquire the same temperature as the body it touches. For the mass of the thermometer ought to be very small in proportion to that of the body it is applied to; in which case the quantity of heat it gives out or receives in the acquisition of the common temperature will be so small as not sensibly to affect the body under consideration; so that the common temperature may

be taken instead of the original temperature required to be found.

K The arithmetical mean temperature between two equal bodies of the same kind, as determined by experiment (115, E) will cause the mercury in a thermometer to stand very nearly at an intermediate equal distance between the stations it would have had at the original temperatures of the two bodies. The increments of expansion in mercury are therefore very nearly as the quantities of heat that cause them. And the quantities of heat added to, or subducted from, a given body in contact with a mercurial thermometer, will be expressed by the number of degrees the thermometer rises or falls.

N Thus far the temperature and heat of bodies of the same kind have been chiefly considered; but if two equal bodies of different kinds and temperature be brought into contact, the common temperature will seldom, if ever, be the mean between the two original temperatures; that is to say, the surplus of heat in the hotter body will be unequally divided between them, and the proportions of this surplus retained by each body will express their respective dispositions, affinities or capacities for heat.

P If therefore a given substance, as for example fluid water, be taken as the standard of comparison, and its capacity for heat be called one, or unity, the respective capacities of other bodies may be determined by experiment, and expressed in numbers in the same manner as specific gravities usually are.

And

And because it is established as well from reason *Q* as experiment, that the same capacity for heat obtains in all temperatures of a given body, so long as its state of solidity, fluidity, or vapour, is not changed; it will follow, that the whole quantities of heat in equal bodies of a given temperature will be as those capacities. And as the respective quantities of matter in bodies of equal volume give the proportions of their specific gravities, so the respective quantities of heat in bodies of equal weight and temperature give the proportions of their specific heats.

A greater capacity for heat, or greater specific heat in a given body, answers the same purpose with respect to temperature as an increase of the mass; or (115, H) the quantity of heat required to be added or subducted, in order to bring a body to a given temperature, will be as its capacity or specific heat (117, R).

The capacities not only differ in various bodies, *T* but also in the same body, accordingly as it is either in a solid, fluid, or vaporous state. All the experiments hitherto made conspire to shew, that the capacity, and consequently the specific heat, is greatest in the vaporous, less in the fluid, and least in the solid state.

The quantity of heat that constitutes the difference *U* between the several states may be found in degrees of the thermometer. Thus, if equal quantities of water at 162° , and ice at 32° of temperature, be mixed, the ice melts, and the common

temperature becomes 32° ; or otherwise, if equal quantities of frozen and of fluid water, both at the temperature of 32° , be placed in a like situation to acquire heat from a fire, the water will become heated to 162° , while the ice melts, without acquiring any increase of temperature. In either case the ice acquires 130° of heat, which produces no other effect than rendering it fluid. Fluid water therefore contains not only as much more heat than ice, as is indicated by the thermometer, but also 130° , that is in some manner or other employed in giving it fluidity. And as fluid water cannot become ice without parting with 130° of heat, besides what it had above 32° in its temperature; so also steam cannot become condensed into water without imparting much more heat to the matters it is cooled by than water at the same temperature would have done.

y The heat employed in maintaining the fluid or vaporous form of a body, has been called latent heat, because it does not affect the thermometer.

w From the consideration of the specific heats of the same body in the two states of solidity and fluidity, and the difference between those specific heats, is deduced a method of finding the number of degrees which denote the temperature of any body immediately after congelation, reckoned from the natural zero, or absolute privation of heat. The rule is; multiply the degrees of heat required to reduce any solid to a fluid state by the number expressing the

the specific heat of the fluid; divide this product by the difference between the numbers expressing the specific heat of the body in each state; the quotient will be the number of degrees of temperature, reckoned from absolute privation of heat*.

To give an example of this curious rule, let it be required to determine how many degrees of refrigeration would absolutely deprive ice of all its heat? The degrees of heat necessary to melt ice are 130,

* This theorem is Dr. Irvine's, and may be proved thus; let s represent the required temperature of the body just congealed, l = the number of degrees that express the heat required to reduce it to fluidity, n = the specific heat of the solid, and m = the specific heat of the fluid. Then, $s + l : s :: m : n$.

Whence $s = \frac{l n}{m - n}$ = the temperature from the natural zero in thermometrical degrees of the fluid (117, v). But because the actual fall of the thermometer is to be produced by cooling the solid, we must pay attention to its capacity (117, s). The quantity of heat required to produce a given change of temperature in a body is as its capacity, and consequently the changes of temperature, when the quantity of heat is given,

will be inversely as the capacities : therefore $n : m :: \frac{l n}{m - n} : \frac{l m}{m - n} = s$. Which is the rule given in the text.

If the data l , m , and n , be accurately obtained by experiment in any one instance, and the difference between the zero of Fahrenheit's scale and the natural zero be thence found in degrees of that scale, this difference will serve to reduce all temperatures to the nomenclature which commences at the natural 0. So that s being known in all cases, if any two of the quantities l , m , or n , be given in any body, the other may be like-

wise had. For $l = \frac{s m - s n}{m}$. And $m = \frac{s n}{s - l}$. And $n = \frac{s m - l m}{s}$.

and the specific heats of ice and water are as 9 to 10. The number 130, multiplied by 10, produces 1300, and divided by the difference between 9 and 10 quotes 1300: therefore if ice were cooled 1300 degrees below 32° , or to -1268 of Fahrenheit's scale, it would retain no more heat.

- Z It is unnecessary to point out the many physical causes that prevent either the production or men-
suration of this ultimate degree of cold.
- A Experiments on heat may be made by mixing fluid bodies, by placing them in a vate, whose temperature, volume, and specific heat or capacity are known; or by placing them in contact with ice at 32° ; in which last case, the quantity of ice melted by a body hotter than 32° will be in proportion to the quantity of absolute heat that causes this difference of temperature.
- B Much care is required to prevent occasional circumstances from influencing the results of these experiments. The masses, specific heats and temperatures of the vessel and thermometer made use of, as well as the temperature of the surrounding atmosphere, must be attended to. The thermometers must be very sensible, and give the temperature to tenths of degrees. The temperature of the mixture must be taken in various parts of the vessel, and its rate of cooling ascertained at different periods, in order to infer the common temperature that would have taken place if the surplus of heat could have been equally diffused at the first instant of the mixture. When the melting of ice
is

is made use of, it is necessary that the ice exposed to the contact of the heated body should be defended from the action of the external air, by being included in a vessel surrounded on all sides with other ice at 32° , and the temperature of the room ought not to be much colder than 32° , lest the melted ice should be again frozen, instead of running into the vessel prepared to receive it.

The chief advantage which the opinion that heat, **c** is caused by mere vibration possesses, is its great simplicity. It is highly probable that all heated bodies have an intestine motion or vibration of their parts; and it is certain that percussion, friction, and other methods of agitating the minute parts of bodies will likewise increase their temperature. Why, then, it is demanded, should we multiply causes, by supposing the existence of an unknown fluid, when the mere vibration of parts, which is known to obtain, may be applied to explain the phenomena? To this it is answered, that mere motion will not **d** apply to the phenomena: for, among other facts, water at 32° contains more heat than ice at 32° , and ought therefore to possess more vibration, yet it does not communicate more to the thermometer. A part of its motion must consequently be latent or incommunicable, which is an absurdity.

A happy explanation of the manner in which the **e** temperature of a body is raised by friction or percussion, has been given* on the supposition that heat is matter.* If the parts of a body containing any

* By Mr. Kirwan.

fluid be made to vibrate strongly and irregularly, they will expel a part of the fluid out of the pores, provided the fluid be not sufficiently compressed to move in correspondence with the vibrations. For in this case a vibrating particle may be considered as if its dimensions were encreased, which is in effect the same thing as if the pores of the body were diminished. The capacity of the body will thus be diminished, and consequently its temperature will be increased (117, s).

- F** All the changes of temperature from the most intense cold to the utmost violence of ignition may be explained from the changes the capacities of bodies, and consequently their specific heats, undergo in the several chemical processes. For universally, whenever the capacities of bodies are diminished, either by freezing or condensation, (117, r) by friction or percussio, (121, e) or by a change in the chemical combination, then the temperature is increased (117, s). And on the contrary, the temperature is diminished, or bodies become cold whenever their capacities for heat are increased.
- H** Thus, in the solution of various saline bodies in water, cold is produced; because the capacity of the salt being increased (117, r) by its becoming fluid, while the absolute quantity of heat remains the same, its temperature must be diminished (117, s). Consequently, the common temperature of the melted salt and water must be lower than it would have been if the salt had not been dissolved (113, y).

For

For the same reason a mixture of snow and salt, applied at the outside of a vessel containing water, produces a degree of cold that congeals the water, or would cause a thermometer to fall far beyond the freezing point. The snow and salt are rendered fluid by their mutual action on each other; their capacities for heat are increased, their temperatures consequently diminished, and the water frozen by the loss of the heat it imparts to produce a common temperature.

So likewise, if a small glass vessel, containing water, be constantly wetted on the outside with ether, the quick evaporation of this last fluid will produce a degree of cold that will in a very short time freeze the included water. For the specific heat of the ether, when converted into vapor, is so great, that its temperature becomes very low, and cools the water even below freezing.

The instances of cold produced by evaporation are exceedingly numerous. From this cause it is that water is commonly about two degrees colder than the surrounding air; that damp clothes produce such chilling effects; that a wet hand, even though wetted with warm water, soon becomes colder than the other that remains dry, &c. &c.

The specific heat of atmospherical air is found by experiment to be considerably greater than that of air which is expired from the lungs of an animal. The air therefore undergoes a change in the lungs, which diminishes its capacity and must consequently increase its temperature. It is found also, that
the

the capacity of blood for heat is diminished in its course from the arteries to the veins. From these causes the temperature of the animal is continually increased. But the evaporation of perspirable matter increases with the temperature, and produces cold. The equilibrium of these actions appears to be the reason why the temperature of any one species of animal is nearly the same in all climates. Animals that have no lungs are of the same temperature as the surrounding medium. In cold countries the effects of perspiration, and the contact of the circumambient air are rendered less by the clothing, as thick fur, hair, &c. that envelope the native animals, and are from necessity made use of by the human species.

- N The specific heat of combustible matter is not considerable; the specific heat of atmospheric air is much greater than that of air which has served the purpose of combustion. Suppose now that by any means the temperature of a combustible substance be raised to such a degree as that the chemical process, which changes the capacity of the air, may go on, the temperature of the air will be raised in proportion as its capacity is diminished, its heat will be imparted to, and still more increase the temperature of the combustible body. A very high degree of temperature will be produced, which will be greater in proportion to the specific heat of the air, the quantity decomposed in a given time, and less in proportion to the facility with which it is absorbed or conducted away by

by other bodies. This process is called combustion, when it is carried on with such rapidity as to cause the body to emit light, at which time it is said to be ignited; and it will continue till the principles of the body are so changed or dissipated as that it can no longer make any change in the capacity of the surrounding air.

The friction of one piece of wood against another, in a turner's lathe, produces heat and flame. A nail may be hammered till it becomes red hot. When flint and steel are struck together, minute portions of the steel are knocked off, in so high a degree of heat, that they are actually burned, and upon extinction are seen, with the magnifier, to consist mostly of hollow balls of a black or greyish metallic colour, and about the one hundredth of an inch in diameter. When the sun's rays are thrown, by a burning-glass or mirror (1. 325, N), on any substance, they exceedingly increase its temperature, and produce the most astonishing effects. In all these phenomena the temperature seems to be raised, at least in the beginning, by the diminution of capacity, which is a consequence of the agitation of the minute parts of bodies.

When water, or any fluid, is heated, the quantity evaporated in a given time becomes greater, because the heat which the greater capacity of steam demands is more readily supplied. The greater evaporation diminishes the augmentation of temperature the fluid acquires, and at a certain period entirely destroys it. This period or temperature,

ture, called the boiling point, is lower, the more easily evaporable the fluid, and will vary in the same fluid, accordingly as the evaporation is more or less easily performed. Thus spirit of wine boils at 180° , water at 212° , mercury at 600, and other liquids at other points respectively; at which they acquire the greatest heat they are capable of sustaining without being converted into vapor in the open air of a mean density. But if the evaporation be impeded, either by the fluid being included in a closed vessel, or by the increased pressure of a denser atmosphere, the fluid will acquire a higher temperature; and, on the contrary, if the atmosphere be light, or the fluid heated in *vacuo*, the boiling temperature will be lower*.

* The theory of heat, as here explained, is due to the immortal Dr. Black, and has been improved and illustrated by Dr. A. Crawford, Dr. Irvine, Mr. Kirwan, Professor Wilkie, Mr. Watt, Mr. Magellan, &c.

C H A P. II.

A DESCRIPTION OF THE METHODS OF APPLYING
HEAT TO CHEMICAL PURPOSES.

THERE are few substances found in a natural state whose constituent parts cannot be separated from each other by the methods used in chemistry. One of the principal methods consists in altering the temperature of bodies.

A great number of bodies are found to be capable of the solid, the fluid, and the vaporous or highly elastic form, accordingly as they contain less or more heat. The temperature at which solids become fluid is exceedingly various in different substances, as is likewise the temperature at which the internal parts of fluids begin to take a vaporous form, and escape with ebullition. The number of degrees of temperature comprehended between these two points of freezing and boiling is not governed by any relation yet discovered between these phenomena and the other properties of bodies. Thus mercury freezes at 49° below 0, and boils at 600° ; the interval being 649° ; water freezes at 32° , and boils at 212° , the interval being 180° ; spirit of wine freezes at 52° below 0, and boils at 180° , the interval being 232° . It is probable that all bodies whatsoever are capable of the three states of solidity, fluidity, and vapor; but that in many instances the

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the freezing or boiling points may lie at temperatures not obtainable by any means in our power.

T Bodies that assume the vaporous state at a lower temperature are called volatile, when compared with such as require a greater degree of heat for the same purpose. Such bodies as either cannot be made to rise in vapor, or require an intense heat to raise them, are called fixed.

U It is easy to conceive how the parts of bodies may be separated from each other by change of temperature. Thus, if soap be dissolved in spirits of wine, and the temperature be rendered lower, the soap will assume a concrete form, and be separated long before the fluidity of the spirits can be affected. Water mixed with spirits is converted into ice by cold, and separated for the same reason. Again, if a mixture of copper and lead be exposed to a heat gradually increased, the lead will be melted first, and will run from the copper, leaving it in the form of a porous mass: or if brass, which is a mixture of copper and a volatile semi-metal called zinc, be exposed to a considerable heat, the zinc assumes the vaporous state, and leaves the copper alone. So likewise quicksilver is separated from gold, water from clay, &c.

V The purposes of chemistry are in general much better answered by raising than by lowering the temperature of bodies. The most usual method of heating bodies is, to place them in communication with others in a state of combustion; that is to say, place them near a fire. The vessels and

furnaces made use of are various, according to their several applications.

When substances of considerable fixity are to be exposed to heat, or when the volatile parts of bodies are proposed to be dissipated into the air, open vessels are used. The common culinary utensils of copper or iron answer these intentions where the matter to be operated upon will not corrode them, and the heat is not required to be very great. Glass vessels are the most cleanly, and may be used in a great variety of processes. They have the advantage of resisting the action of most corroding matters, are impermeable to air and vapor, and their transparency affords the valuable convenience of beholding the changes that happen within them. In higher degrees of heat, such as would soften or melt glass, it is necessary to use vessels of earth, or other matter.

A matras, is a kind of bottle shaped most commonly like a Florence flask, though its figure is various, according to the uses it is intended to be applied to, fig. 150, letter c. A cucurbit, is a vessel nearly of the same figure, but with a long neck, fig. 150, letter A. It is made either of metal, glass, or earthen-ware. A crucible, is a pot made use of for melting metal and other similar purposes. It is made either of platina*, forged iron, black lead,
or

* Mr. Achard's process for making crucibles of platina is as follows: Take equal quantities of platina, white arsenic

or earth. A cupel, is a shallow crucible, made of calcined bones, and used by assayers. The large crucibles of this kind, used by refiners, are called tests.

y In most operations where the volatile parts of bodies are proposed to be separated and preserved, it is necessary to use closed vessels. To the cucurbit A, fig. 150, is adapted the head B, denoted by the dotted line: from the head proceeds a tube that communicates with the matras c, which in this case is called the receiver. The head B is inclosed within a tub or vessel, called the refrigerator. The whole apparatus thus disposed is called an alembic or still. The matter to be operated on is put into the cucurbit A, and the head fitted on: cold water is poured into the refrigerator; and the receiver adapted to the tube, by means of an earthy paste, called lute. The fire being then lighted, forces the volatile fumes into the head B, where they become condensed by the cold, and flow in a liquid form into the receiver c. This process is called distillation.

z When distillation is performed in the large way, a very large tub or vessel is substituted instead of

and salt of tartar, and expose them to a strong heat, till they melt. This matter, when cooled, must be reduced to powder, with which the mould of the vessel intended to be formed must be filled. A strong heat quickly raised, under a muffle, and continued for some time, will again fuse the mass: the arsenic and salt of tartar will be forced off, and the platina will be left alone in the form desired.

the

the refrigerator, and the vapors pass through a spiral pipe called the worm. Thus fig. 151, *A* is the body of the still, *B* the head, *D* the worm-tub containing cold water, and the dotted lines represent the pipe called the worm, terminating at *E*, where the condensed vapors run out in a liquid form.

But there are many matters required to be distilled that are not sufficiently volatile to pass into the receiver by either of these methods. In such cases the refrigerating part is omitted, and the cucurbit is made with its neck on one side, as in fig. 152. It is then called a retort, and the receiver is usually luted to the neck. Most of the experiments made in the small way may be performed with retorts, if attention be paid to apply more or less heat, according to the volatility of the products expected to come over.

When volatile substances are raised by heat in a dry form, the process is called sublimation. If the sublimed mass has a loose powdery form, it is called flowers. Such are the flowers of brimstone, of benjamin, &c. An ordinary cucurbit, or matras, will serve for the sublimation of such bodies as are not very volatile. When they are more volatile, the head *B* of the alembic is a proper receptacle, fig. 150, especially if moist products arise and are required to pass at the same time into the receiver *C*. In other cases the receiver is not annexed, and a number of heads are fixed one above the other communicating by necks, the uppermost

uppermost one only being closed at top. Many sublimates are attached to the chimnies of furnaces, among which common foot is a familiar instance.

- c The construction of furnaces is as various as the purposes they are designed to serve. A lamp, supported at different distances below any chemical vessel, or burning with a variable number of wicks, is very useful where low degrees of heat are intended to be applied. Chemical vessels may be plunged to greater or less depths in a pot over the fire containing either water, mercury, a mixture of mercury and lead, sand, iron filings, or other matter capable of sustaining heat. These substances, interposed between the vessel and the fire, compose what is called a bath, and are of excellent use for imparting an uniform heat, not subject to the sudden vicissitudes experienced by vessels exposed to a naked fire. Without this contrivance glass vessels would often fly or crack. Glass or earthen vessels, intended to sustain a greater heat than can be given by means of a bath, are usually* coated with a mixture consisting chiefly of clay and sand.

* The valuable method used by Mr. Willis, of Wapping, to secure or repair his retorts used in the distillation of phosphorus, deserves to be mentioned here. The retorts are smeared with a solution of borax, to which some slaked lime has been added, and when dry, they are again smeared with a thin paste of slaked lime and linseed oil. This paste being made somewhat thicker, is applied with success during the distillation, to mend such retorts as crack by the fire.

Fig.

Fig. 153, represents the wind-furnace, or air D melting furnace. In this section A denotes the ash-hole, B the grate, C a crucible placed on the grate, F a stone covering the upper part of the fire-place, G the side-communication between the fire and the chimney E H. D is a cupel occasionally placed in the current of flame that issues from the fire. The fuel and pots are introduced at the hole F. The effects of this furnace are easily explained. Combustion (124, N) is more rapid and intense in proportion to the quantity of air supplied and decomposed. The pressure of the atmosphere upwards at B is greater than the pressure of the column that acts downwards, because the lower part of this last mentioned column consists of a rarefied portion of air included in the cavity D C G E H. The lighter column will therefore ascend with a velocity so much the greater as its rarefied part is longer and more rarefied. If therefore the fire be large, and the chimney high and sufficiently narrow for the air to pass through before it is much cooled, a very powerful degree of heat will be produced.

Fig. 154, represents the reverberatory furnace. B By means of the dome B the flames are driven back, and made to play round the retort C; and occasionally the fuel may be heaped round the retort, so as nearly to fill the dome.

There are many other furnaces, for the making of glass, the roasting of ores, and extracting their contents, the firing of pottery, and other nume-

rous purposes. For the description and use of these, larger treatises must be resorted to. The philosophical chemist may in general perform his operations without being under the absolute necessity of using furnaces constructed on purpose, or preparing any large apparatus of vessels. A tobacco-pipe is a very useful kind of crucible, with which many experiments may be well made in a common fire, especially with the assistance of a pair of double bellows. Common chafing dishes, small iron stoves, or the larger kind of * black lead pots may be applied to purposes of the most extensive utility by an ingenious operator. Bottles of various shapes, and other vessels, may be found in common use well suited to the performance of chemical experiments: such are apothecaries phials, Florence flasks, earthen pans, &c.

- ¶ The blow-pipe is an instrument of great use in the chemical examination of mineral bodies. This may be procured in the shops, and consists of a tube of about ten inches long, formed as in the figure (fig. 155). The aperture A is about a quarter of an inch in diameter, and is intended to be applied to the mouth in blowing; the other aperture B is very small, so that the wind issues out in a fine stream. If now a candle be snuffed, and the wick turned a little on one side, the flame may, by this stream of air, be directed upon any small

* The method of constructing cheap and portable furnaces out of black lead pots, is described at large in "Lewis's Philosophical Commerce of Arts."

body, and is sufficiently active to produce every change that the strongest furnace can effect on larger bodies.

The common blow-pipe is subject to two principal inconveniences; the first is, that the moisture of the breath becomes condensed in the tube, and occasionally spirting out of the aperture *B*, either checks the burning of the flame, or produces other disagreeable accidents; the other is, that the aperture *B* being invariable, can only be adapted to a flame of one particular magnitude, whereas a larger flame requires a larger aperture. The blow-pipe best suited to philosophical purposes is provided with a ball *c* (fig. 156) in which the vapors are detained, instead of passing through the aperture *B*: and the piece *B* may be unscrewed, and changed for another, accordingly as the aperture is required to be varied. If the aperture be not round and smooth, the flame will be ragged and irregular.

The body to be urged by the flame, directed and excited by a blow-pipe, ought not to exceed the size of a grain of pepper. The best supporter to place it on is a smooth close piece of charcoal, which answers perfectly well for all matters that do not sink into its pores, nor are changed by its inflammable principle. In such cases as the charcoal cannot be used, it is necessary to be provided with a small spoon, either of pure gold or pure silver, there being no other metals that admit of being worked with facility, but are changeable by heat.

- K** The advantages attending experiments made with the blow-pipe are many. They may be made in a very short time in any place, by an apparatus that admits of being carried in the pocket. The quantity required of any material is so small, that they are performed at a very little expence. And the whole process, instead of being carried on in an opaque crucible, is visible from beginning to end. They are therefore of great utility in examining bodies where experiments in the large way cannot easily or conveniently be made, and where they can, these small trials previously made are often of service to indicate the best way of conducting them*.
- L** If the blow-pipe be used with the pure air, called dephlogisticated air, obtained by distillation from nitre, or other salts, it produces a greater degree of heat than can be obtained by any other method yet discovered, unless we may except the heat in the focus of a few of the most capital burning lenses.
- M** The burning glass or mirror is seldom used in chemistry, except on such occasions as do not admit of the other methods of heating bodies.

* The use of the blow-pipe is explained by Gustav von Engeström, in a treatise annexed to the English edition of Cronstedt's Mineralogy, and also by Bergman, in his *Treatise de tubo ferruminatorio*, in which the habitudes of a great number of bodies in the fire, either with or without addition, are given. The English reader will find this excellent work at the end of Cullen's Translation of Bergman's Essays. London. 1784.

C H A P. III.

AN EXPLANATION OF THE NATURE AND EFFECTS
OF THE ELECTIVE ATTRACTION, OR CHEMICAL
AFFINITY.

IT has been sufficiently shewn in the former parts of this Treatise, that the parts of bodies have a tendency towards each other, which is generally denoted by the word Attraction. Were it not for the effects of this power, the motions of all bodies would be performed in right lines (1. 21. P), and their parts would be separated from each other by the smallest impulse. It is, in fact, impossible to form a notion how the universe could subsist in its present form without it.

The first rule of philosophizing (1. 6) leads us to enquire whether the various effects of attraction that take place in natural phenomena be consequences of one and the same principle, or, if more causes than one should be concerned in producing them, how far the operation of each extends. If the attraction of cohesion were the same as gravitation, its power would follow the same ratio of the distances of bodies from each other (1. 207), and would be sensible at very considerable intervals of space; but as it is perceived only at extremely small distances, and even gives place to repulsion when the interval is increased (1. 47. 2), it seems necessary to consider it as a distinct property of matter,

matter, or, at least, as the effect of some other cause.

- D** Whether the attraction of cohesion, or the power that resists the separation, by mechanical means, of the parts of solid bodies, be the same as those attractions which, on account of their being exerted more strongly between two given bodies, than between one of the two and a third of a different kind, are called elective attractions, or chemical affinities, has not been well decided. The enumeration of a few simple propositions respecting attraction, generally considered, may tend much to elucidate this business.
- E** As the attraction of gravitation is taken to be a general property of matter, acting according to the masses of bodies (1. 18. 1; 26, A), and we do not suppose a variety of attractions, but of densities, in bodies that are variously heavy, so may one general property cause the particles of bodies to adhere together, though its intensity, varying with the density of those particles, may produce various effects.
- F** In all the phenomena of attraction, the force is greater when the distance is less: and it is clear, that particles of the same mass and density may have various figures, some of which will admit of a nearer approach of their centers, when their surfaces are in contact, than others. Such particles as by their figure can admit of their centers coming nearer together, will adhere more strongly on that account.
- H** Against the truth of the position, that the attractions displayed in the cohesion of bodies, and in chemical

chemical operations, follow the density of the particles, it is no objection to say, that the hardness and specific gravity of bodies are governed by no common law: for the hardness, according to this doctrine, depends on the density, magnitude, and figure of the particles, and the specific gravity on the density of the particles, and the proportion between their aggregate bulk and the bulk of the space occupied by the pores of the bodies. And as these attributes do not depend on each other, but may vary indefinitely, there is no necessary relation between hardness and specific gravity.

The adhesion of like parts, by which a body is formed of the same kind as the parts themselves, is called aggregation; but the adhesion of parts, not of the same kind as each other, by which a body is formed, having properties different from those of the parts, is called combination. It does not appear that combination is performed by any power different from the attraction of cohesion, by which aggregation is allowed to be produced; or, in other words, the attraction of cohesion, and of chemical affinity, appear to be the same power exercised in different circumstances.

If a particle of matter be surrounded by others of a certain kind in contact with it, it may still attract and retain others, forming a second enveloping stratum, and so on, according to the force of attraction it exerts on such particles. But at a certain period the accumulation will cease, on account of the attraction being inconsiderable beyond a limited

- o limited distance. At this period, if particles of a third different kind be presented, they may be attracted and retained by the central particle notwithstanding, provided its attraction to these last
- p be stronger than to the former: and accordingly, as these last are more weakly or strongly attracted, they will either form an additional stratum without, or will be urged inwards, so as to displace the others by forcing them out of the sphere of
- q attraction. The phenomena will likewise be different in consequence of the greater or less force of attraction mutually exerted between the particles of different kinds applied to the central particle.
- r A particle surrounded by as many of another kind as it can retain, may be considered as a simple particle with respect to such particles of a third kind, as it can attract and retain without displacing the former.
- s Let a particle be supposed to be surrounded by as many of another kind as it can retain, and also by particles of a third kind, enveloping the former; let the attraction of the central particle be supposed greater in like circumstances with respect to the external kind, than to the kind of particles which are nearest to it, but stronger on these last, merely on account of their proximity; then, if the whole be heated, the respective distances of all the particles will be increased (113, x); this increase may augment the distances of the nearer in a higher proportion than of the remote particles, and consequently cause the attractions of the central
particle

particle on each to approach nearer to equality, or even cause attraction on the external stratum to become greatest; and again, the inner stratum of particles having their interstices rendered larger, may admit the outer to pass through without impediment, and possess the nearer place: that is to say, T heat may cause changes of combination to take place that would not have obtained at a lower temperature.

The simplest parts that enter into the composition of bodies, namely, such parts as have not hitherto been decomposed by any method of analysis, or obtained by the combination of other simple bodies, are termed elements or first principles.

When a combination of two first principles enters v into the composition of a body, by uniting with some other principle or principles, this combination is termed a secondary principle of the body it enters into (140, R).

Thus, when soap is dissolved in ardent spirit a combination is formed into which the soap though not a simple substance, enters as a secondary principle, and from which it may be again separated, by proper methods, in its original form.

When principles are combined in such propor- w tions as to form a compound that exhibits the least possible any of the distinguishing properties of the principles, they are said to be saturated with each other. If either principle exceed this proportion, it is said to be imperfectly or partially saturated, and the other is said to be supersaturated.

For

For example, if spirit of salt, or the marine acid, be added to salt of soda, or the marine alkali; the compound will exhibit acid properties, if the first abound beyond a certain proportion; or if the latter predominate, the alkaline properties will prevail; but if each be in due quantity, the compound will be common culinary salt, neither acid nor alkaline.

- x Mixture is the union of principles, which remain nevertheless in considerable masses that adhere to each other respectively, either by reason of the similar principles having a greater attraction to each other than to the principles of another kind, or because the heat of the mass is not sufficiently great (141, T) to cause that change which would produce an intimate combination of the whole.

Oil and water, when shaken together, do not combine but only mix, because the parts of each respectively attract those of the same kind more strongly than the other: so likewise pot-ash and sand may be mixed without combining, but an increase of temperature in the furnace of a glass-house will cause them to unite, and form the combination called glass.

- y To produce a change in the combination of the parts of bodies, it is in general required that the temperature of the whole should be sufficiently high to melt at least one of the principles.

- z When a fluid combines with another body without losing its fluidity, this last is said to be held
in

in solution, or dissolved, and the fluid is called a solvent or menstruum.

A menstruum saturated with one principle may, notwithstanding, take up another (139, N, 6).

Thus salt may be dissolved in water, and when it is saturated, and will not act on salt, it will dissolve sugar.

When a fluid that holds one or more principles in solution lets one fall upon the addition of some new principle to which the combination has a greater affinity, the principle let fall is said to be precipitated by the newly added principle, which is called the precipitant.

Epsom salt consists of magnesia, combined with the marine acid. If this salt be dissolved in water, and salt of tartar be added, the magnesia will fall to the bottom in the form of a white powder, and the salt of tartar will combine with the acid.

When two principles being united are so separated on the addition of a third, that one of the original principles quits the other, and forms a new combination with the third, the decomposition and new combination are said to be produced by simple affinity.

Common salt, as has been already observed, is a combination of the marine acid with the marine alkali. If oil of vitriol, or the vitriolic acid be added, the alkali will quit its acid to unite by stronger affinity with the acid last added: with which it will form a new salt, called Glauber's salt,

salt, while the marine acid being disengaged, flies off in an elastic form.

- D When two compounds, consisting each of two principles, are presented to each other, and the combinations change the order of their principles, because the attractions of one principle of the one to one principle of the other, and of the remaining principle of the one to the remaining principle of the other, are, together, stronger than the attractions that tend to preserve the original form, the two decompositions, and two new combinations, are said to be produced by double affinity.

Sal-ammoniac is composed of the marine acid, combined with the volatile alkali, or salt commonly used in smelling bottles. If sal-ammoniac in powder be mixed with flaked lime, the marine acid unites with the lime, and the water of the lime joins with the volatile alkali, which rises immediately in penetrating fumes. This mixture being hastily put into a retort, the water and volatile alkali come over together, by the assistance of a gentle heat, in the form of a pungent fluid, called the caustic volatile alkali, or, by apothecaries, spirit of sal-ammoniac with quicklime. In this process it is not simply the attraction of the marine acid to the quicklime, nor the attraction of the water to the alkali that occasions the double change of combination, but it is the united force of both attractions: for if dry hot quicklime, that is to say, quicklime containing no water, be made use of, the sal-ammoniac

as it is not decomposed, the simple attraction of the marine acid to the sticklime, not being sufficient to overcome the attraction of its component principles.

There are many other compounded effects of the mutual attractions of the parts of bodies, in various circumstances. The manner in which the water is for a requisite time, in some experiments with facts, a little more than the usual habits of reasoning, and the manner in which the water is for a requisite time, in some experiments with facts, a little more than the usual habits of reasoning.

Fluids in general, when they are in a state of any substance when the attraction is not so strong, but this is not universally true. The effect of the general fact seems to be, that the attraction of the fluid in solution may be better maintained (213. x) at a higher temperature; that is, partial solution, where all the principles are not taken up, the heat, by volatilizing some principles, may render the solution of the residue more easy, and the reason why in some cases less is taken up by a fluid at a higher temperature at a lower temperature is, probably, that the general effect of heat being so opposite (213. x) the attractions between bodies may operate more strongly than the other causes have taken notice of. But it is probable that none of the cases wherein this effect seems to take place are of a simple nature.

Chemical processes, in which water is a principal agent, are said to be performed in the moist way: those which are performed at high temperatures, and wherein water is little, if at all, concerned, are said to be performed in the dry way.

C H A P. IV.

OF THE FIRST COMPONENT PRINCIPLES OF BODIES,
OR SUCH AS ARE THE MOST SIMPLE.

- H ALL bodies are parts, either of animal, vegetable, or mineral substances. During the life of animal and vegetable substances, various processes, both mechanical and chemical, are carried on within them, by means hitherto very imperfectly explained. The principles that enter into the composition of these are far from being simple. As soon as their structure is, by violence or otherwise, so impaired as to destroy life, the arrangement of chemical principles begins to change. Decompositions and new combinations take place among the solid as well as the fluid parts. The organization of the vessels is destroyed, and after a certain time the whole, as far as observation can follow the processes, returns to the general repository of minerals or unorganized matter, from which it originated, and cannot again be distinguished.
- I „ The simplest bodies are air, water, salts, earths, and inflammables. Many chemical philosophers of the first eminence are now busied in discovering or ascertaining the component parts of these, but the limits of the present work, as well as its intention, will not admit of entering, except occasionally,

tionally, into the consideration either of the facts or theories they have exhibited to the world.

Many substances may assume the aerial form, either from their disengagement by stronger affinity (143, c), or by increasing their temperature. Air is distinguished from transparent vapor by its more permanent elasticity. It is probable that this difference consists in the greater aptitude of vapor for imparting its heat to other bodies, or combining with them. There are several kinds of air that lose their elasticity and combine with water, if presented to them; and there are others that cannot be kept in an elastic form for any length of time, merely because of their aptitude to combine with every fluid that has hitherto been used to confine them.

When air is classed among simple substances, nothing more is therefore to be understood than that a variety of principles are obtainable in this form, much more simple than it is probable they will ever be met with in any other.

Water enters as a simple substance into the composition of many bodies. There are no absolutely unequivocal proofs of its having been changed or decomposed in any chemical process. Yet if inflammable air and pure air be burned together, water is produced which is said to be equal in weight to the quantities of air made use of. Whence it is concluded, that water is composed of those airs combined together in the heat of combustion (141, T), during which act, the latent heat

(118, v. 124, w) that maintained the aerial form is given out.

- o The purest natural water is rain, collected at a distance from trees or buildings. For chemical purposes, water should be distilled in glass vessels, with a heat not sufficient to make it boil, and no more than two-thirds of the whole quantity should be drawn off. The lightest, clearest, and most tasteless water, which lathers well with soap, is purer than such waters as are deficient in these qualities.
- p Salts are such bodies as are dissolvable for the most part in less than two hundred times their weight of boiling water, and more or less affect the organ of taste. They liquefy by heat, which causes them to evaporate, either in part or totally, according to the component parts of the salt, and the intensity of temperature.
- q Simple salts are either acids or alkalis. Compound salts are either combinations of acids with alkalis, which are called neutral salts; of acids with earth, called middle salts; of acids with metals, called metallic salts; or combinations of these with each other.
- r Earths are tasteless brittle substances, differing from salts by their less solubility in water, the distinguishing limit being not founded in nature, but arbitrary. Water at a high temperature, as when confined in the strong metallic vessel called Papin's Digester, will dissolve some, and probably all earths. The substances classed under this title

title are not soluble in the open air in less than between six and seven hundred times their weight of boiling water. They are not susceptible of the metallic lustre. In the fire they are fixed. A low heat does not alter their form or other properties, and simple earths are not fusible alone, by the most violent heat that art can produce.

The well known simple earths are five; calcareous earth, or pure quick-lime; ponderous earth; magnesia; argillaceous earth, or pure clay; and siliceous earth. These earths have never yet been decomposed. Like all other simple substances, they are never found pure, but the methods used in chemistry can easily separate them from the matters they may happen to be either combined or mixed with.

Late experiments have ascertained the existence of several other Earths; which however are neither so plentifully diffused, nor hitherto so well known as to require a place in this Elementary Treatise, except by mere enumeration. These are, the Earth of Adamantine Spar*; the Earth from the Jargon of Ceylon†, both discovered by Klaproth; the fusible Earth from New South Wales, discovered by Wedgwood‡; and the Earth from the Spar called the Strontionite, discovered by Dr. Crawford§. For their distinctive characters and

* Annales de Chimie, I. 183.

† Journal de Physique, for March 1790

‡ Philosophical Transactions for 1790. p 306.

§ Medical Communications, Vol. II. also Phil. Transf. 1784.

properties, the reader must recur to the authorities quoted below.

Every change produced in bodies is evidently the consequence of motions among their parts. When these motions are distinguishable by the senses, the effects are called mechanical; in most other cases they class with chemical processes. One of the most striking and obvious means of producing the latter change in bodies, consists in altering their temperature. The means of doing this has been explained in the chapter upon heat. Whenever the temperature of bodies is raised so as to render them luminous, a remarkable difference is seen in their habitudes when left to themselves. Some of these ignited bodies gradually become cooled down to the temperature of the surrounding air, without having undergone any notable change. Others, on the contrary, provided respirable air be present, not only retain their luminous state and temperature, but become hotter, are internally agitated as to their parts, and do not return to the common temperature until a complicated chemical process has been effected to the entire destruction of the original form and most of the properties of the body itself. This process is distinguished by the name of combustion, and the body thus changed is said to have been burned. It is evident that all bodies whatever may be classed either as combustible or incombustible; and it is equally clear that the doctrine of combustion must constitute a large part of chemical science.

6

Wherever,

Whenever we discern an eminent property in any substance submitted to our observation, we either commit the fact to memory, to be applied in our future reasonings, or else we deduce its existence from some former fact supposed to have been established in the same manner. Thus in the instance before us, philosophers, after collecting as much information respecting combustion as they could, were formerly content to rank combustibility among the properties of a few bodies, such as oils, sulphurs, and bitumens, and accounted for the combustibility of other matters by supposing them to contain more or less of these ingredients. This doctrine was rendered more general by the celebrated chemists Beccher and Stahl, and their numerous followers. Their theory is well known by the name of the Doctrine of Phlogiston. According to the most modern arrangement of this theory, a body or chemical principle eminently or rather solely combustible, always identical, capable of passing from one combination to another, but never yet exhibited in a distinct state, is the cause of combustibility in all bodies which contain it. It has been ascertained by our cotemporaries that combustion does not take place but when respirable air is present, and that this air is absorbed and enters into combination with the body during its combustion. The phlogistian philosophers have been compelled by this fact to modify their theory, and to affirm either that the phlogiston itself unites with the air, and forms a compound which, according to cir-

L 4 circumstances,

cumstances, unite with the residuum or flies off, or else that the air itself unites with the residual matter, while the phlogiston escapes. The increase of temperature which takes place during combustion, is in every theory accounted for from the consideration of the changes of capacity that take place during the process, and more especially it is ascertained from experiment and inference that the air in condensation gives out a large quantity of heat.

A respectable number of modern chemists have altogether rejected this modification of the ancient doctrine of sulphurs and oils. As it is evidently no advance in theory to say a body is combustible because it contains sulphur or phlogiston, which are also said to be combustible, it will follow that our enquiries ought to be directed to the events which take place with these last bodies, or at least with such as can be unequivocally submitted to observation. In all such clear and unexceptionable cases the facts are simply, that the combustible body and respirable air are brought into contact; that the temperature of the body is raised by communication or by other means; that at the requisite elevation of temperature the respirable air begins to unite with the body itself, at the same time that heat and light are developed, that this process goes on until the whole of the respirable air is absorbed, or until the body is saturated with that principle; and that the new product is in all cases which admit of weight or mensuration equal to the weight of the air which has disappeared, added to that of the body

body which was subjected to combustion. The experiments from which these facts are deduced are the combustion of phosphorus with vital air in a closed vessel, and the calcination or combustion of mercury and other metallic bodies, for which the writings of Lavoisier and the notes of the academicians upon Kirwan's phlogiston, may be consulted. The preceding circumstances do not appear to teach us any thing further than that respirable air and a combustible body have united, and that light and heat have appeared. Rejecting therefore at present the consideration of the light and heat, which, if they be distinct substances, can scarcely be classed among principles of density sufficient to be weighed or measured, it may be inferred that combustion consists in, or at least follows, whenever there is a rapid union of vital air with any other body. This is the pneumatic or antiphlogiston doctrine, which though not firmly established in all its parts, yet being much more simply and distinctly deduced from direct observation than the doctrine of Stahl, is likely to be universally received as soon as the habits of philosophizing according to the old theory shall have been eradicated.

The simplest inflammable substances are, inflammable air, diamond, plumbago, sulphurs, and metals. More compounded inflammable matter are, hepatic air, spirits, ether, oils, bitumens, coal, and generally all animal and vegetable substances in their natural state.

When

w When a metal is subjected to combustion or any other equivalent process, it loses its malleability, assumes many of the properties of an earth, and no longer exhibits the lustre peculiar to this class of bodies. In this state it is called a calx, and forms combinations with saline substances. When the metallic state is restored to a metallic calx, the metal is said to be revived.

Every substance, which passes from a fluid to a solid state, appears to have its parts arranged in a symmetrical order, that extends to a greater or less number of particles, accordingly as the influence of external circumstances, or the rapidity with which the change of state is performed are concerned in the process. Thus we see that most minerals; saline combinations, whether obtained by solution or sublimation; and metals, if suffered to cool slowly, have their peculiar forms, though in some more evident and distinguishable than in others. This property, called crystallization, is by some distinguished into two kinds: the one made in a menstruum, as salt crystallizes in water, and the other by mere cooling, as when water freezes alone. Those who affirm that heat is matter, imagine it to be the medium in which this last crystallization is performed.

It would be of singular advantage in mineralogy, v and every other science related to chemistry, if the external appearance and figure of bodies could be applied to the purpose of knowing what class they belong to. This is indeed done with some success,

success, by such as have opportunities of examining many specimens; but no concise general rules have yet been established, on account of the exceedingly great number of exceptions that arise from circumstances, or differences in the compound, either too minute for the chemical analysis to ascertain, or apparently too insignificant to excite the attention of the observer.

C H A P. V.

THE METHOD OF MAKING EXPERIMENTS ON VARIOUS KINDS OF AIR.

EXPERIMENTS to be made with the various kinds of air require an apparatus of vessels proper for confining it. The chief are those we are about to describe.

Fig. 157, A, is a tub for containing water. In this tub is fixed a shelf κ, κ , so placed that it may be about an inch below the surface of the water, when the tub is nearly full. B and F are cylindrical glass jars. C is a bottle, into the neck of which the bent tube D is fitted, by grinding. Suppose now that the vessel B be plunged in the water, so as to be filled, and afterwards raised, with its mouth downwards, and placed on the shelf κ , it will continue full of water on the principle of the barometer: if its rim be made to overhang the edge of the shelf, it will be easy to introduce

introduce the end of the tube *b* beneath it; and if the vessel *c* contain such matters as by their action on each other furnish air, the air will pass through the tube *b*, and rise to the top of *a*, expelling more or less of the water. A candle may be applied beneath *c* in cases where heat is wanted.

x *z* is a small retort, supposed to contain materials that afford air to the vessel *r*.

y Air may be transferred from one vessel to another by the help of a glass-funnel under water. Thus the vessel *g* being supposed to be previously filled with water, and placed on the shelf, over a hole in which the funnel *n* is stuck, the air may be poured out of the vessel *i* through the funnel into *g*.

z Many kinds of air combine with water, and therefore require to be treated in an apparatus in which quicksilver is made use of. This fluid being very ponderous, and of considerable price; motives both of convenience and oeconomy, require that the apparatus should be made smaller than when water is used.

A Where the change of dimensions that follows from the mixture of different kinds of air is required to be ascertained, a graduated tube (fig. 158) is made use of. And because the salubrity of common air is supposed to be determinable by this means, such a tube is called an eudiometer tube. There are apparatus of a less simple construction, which are intended to answer the same purpose, and are called eudiometers.

Fig. 159 is a glass-apparatus for impregnating **B** water with fixed air. It consists of three vessels. The lower vessel **c** has an orifice or neck **d**, with a ground-stopper; the vessel **b** is fitted by grinding, into the neck **h** of the vessel **d**. At **e** is a glass-cock; and in the lower neck of the middle vessel **b** is a valve, opening upwards. This valve is composed of two tubes of glass, with a moveable plano-convex lens between, as represented in fig. 160. The upper vessel **a** is fitted, by grinding, into the neck **i** of the vessel **b**. It terminates below, in a tubular form **g**, and is closed at top by the stopper **f**. The process is thus conducted. Pieces either of marble or chalk are put into the lower vessel **c**, and water poured thereon; the vessel **b** is then filled with water, and placed on **c**, by inserting its lower part in the neck **h**. The empty vessel **a** is placed in like manner on **b**, its stopper **f** being in its place. Lastly, a small quantity of oil of vitriol is poured into the orifice **d**, which is then closed. The vitriolic **C** acid combines with the earthy part of the marble or chalk, and disengages the fixed air that entered into its combination, which, of course, passes through the valve at **h**, to the upper part of the vessel **b**. The displaced water being prevented from descending by the valve, is forced up through the tube **g** into the vessel **a**; at the same time that the common air in this last vessel is partly condensed, and partly escapes, by lifting the stopper **f**, which is ground conical, to prevent its sticking. When the water in **b** has descended as low as the orifice of **g**, the fixed air passes
up

up through the tube instead of water, and expels the common air from the upper part of A. Both surfaces of the water being thus exposed to the fixed air, this fluid gradually absorbed, gives the water that lively subacid taste, which is the distinguishing character of the Pyrmont water.

- D · Those who are not provided with the apparatus here described, may supply its place by the help of utensils that are every where to be met with. A (fig. 161) is a half-pint phial; B a bladder, whose neck is tied round a cork that fits the mouth of A, and has a hole made through it with a heated wire. The same bladder is seen at D, with a bent tube E stuck in the hole of the cork. In the phial A is chalk, with water acidulated with oil of vitriol. The fixed air that rises is received in the bladder, previously moistened. While the bladder is filling, a quart bottle C, full of water, is to be inverted into the basin F, which likewise containing a little water, prevents the common air from rising into C. As soon as the bladder is filled it is taken from the phial A. The tube E is inserted, and its orifice carefully placed under the mouth of the quart bottle C, as in the figure. The bladder being then pressed, the fixed air ascends to the upper part of C at the same time that an equal bulk of water descends into the basin. By agitating the bottle C, without withdrawing its neck from the water, the fixed air becomes absorbed in a few seconds, and the water reascends. This process being repeated two or three times,

times, the water becomes saturated, as appears by the fixed air being no longer absorbed.

Though this method possesses the advantage of convenience, to such as cannot use the other, yet it does not produce so strong an impregnation; partly, because the water takes up more fixed air when condensed by pressure, and partly, because in this last method the water in the basin being exposed to the atmosphere, gives out a portion of the fixed air it contains.

C H A P. VI.

CONCERNING WATER, ACIDS, AND ALKALIS.

THE properties of water have been so often adverted to in the former parts of this Treatise, that it is the less necessary to treat them diffusively in this place. Water in freezing usually assumes a symmetrical form, which is that of needles crossing each other at angles of 60° or 120° . This arrangement of the parts occasions the mass to occupy considerably more space than before, and the expansion, which is performed almost instantly, is effected with such prodigious force, that no vessel has yet been used that can withstand it. Bomb-shells and gun-barrels have been broken by freezing water in them.

From this expansion it is, that ice is specifically
less

less heavy than water, and consequently floats upon its surface.

It is equally difficult to ascertain any limits to the force with which water in a state of vapour may be expanded by heat.

- I Water is so universal a solvent, and enters into so many chemical processes, that most philosophers overlook its agency, in the consideration of facts it is concerned in: and to this circumstance it is, perhaps, chiefly owing, that its component parts have hitherto been undiscovered.
- K Acids are salts, which are sour to the taste. They convert the blue colour of tincture of heliotropium * to a red, and cause an ebullition or escape of air, if applied to chalk or mild alkalis. The affinity of the purer acids for water is such, that for the most part they cannot be obtained in a concrete state; and their action on other substances is so general, that they are never found pure, but require the assistance of art to render them so.
- L The acids found in the mineral kingdom are, the aerial acid or fixed air; the vitriolic acid, known in commerce by the name of oil of vitriol; the nitrous acid, called spirit of nitre; the marine acid, called spirit of salt; the acid of spar, or sparry acid; the acid of borax, called ~~salutative~~ salt; the succinous acid, or acid of amber; the phosphoric acid; the acid of molybdena; the acid of arsenic, and the acid of tungsten or wolfram.

* Called litmus by the dyers.

The vegetable kingdom affords many acids: *m* those which have been examined chemically are vinegar, the acids of tartar, of sugar, of sorrel, of lemons, and of benjamin.

The acids peculiar to the animal kingdom are *n* the acids of milk, of sugar of milk, of ants, of talow and of prussian blue.

Vegetable and animal acids are so far from being *o* simple, that many of them are resolvable into air by the process of distillation. The aerial and the phosphoric acids, though enumerated in the mineral kingdom, are also obtained in great quantities, both from animal and vegetable matters.

Modern chemistry has discovered many acids, *p* and there is good reason to expect that their component parts will be disclosed by the labours of our cotemporaries; but the alkaline salts still remain no more than three in number, and have not hitherto been treated in any method that promises a satisfactory analysis. They have a peculiar caustic urinous taste, and convert the blue colour of the tincture of heliotropium to a green.

The vegetable fixed alkali, impure samples of *q* which are met with in commerce, under the names of salt of tartar, pot-ash, pearl-ash, &c. is most plentifully obtained from vegetable substances.

The mineral fixed alkali is met with in an im- *r* pure state, in commerce, under the names of kelp, barilla, soda, or salt of soda. It is found *x* in the earth, either pure or in combination with other matters. The sea contains immense quantities of

it, where it is one of the constituent parts of common salt, and it is the most profitably obtained from vegetables that contain sea-salt.

s The volatile alkali is sold by the apothecaries under the name of smelling salts, or sal-volatile, in which state it is combined with a large portion of aerial acid. It is most plentifully obtained from animal substances, being combined in them with other principles. The process of putrefaction throws it off into the air, together with other volatile matters that vitiate, and often disguise its smell.

T Alkalis, combined with the aerial acid, are said to be mild; when they are divested of every acid they are called caustic.

C H A P. VII.

THE PROPERTIES OF SIMPLE OR PRIMITIVE
EARTHS.

CALCAREOUS earth exists in a considerably pure state in common quicklime. If pounded chalk be several times boiled in distilled water to separate by solution such marine matters as may be found in it, the remainder will consist almost entirely of calcareous earth, united to about an equal weight of fixed air, or aerial acid. If distilled vinegar be added to this powder, it will form a saline combination with the earth only, at the same time that the fixed air, assuming an elastic form, flies off. To this solution, decanted from the impurities, mild volatile alkali being added, the alkali will unite with the vinegar, while the calcareous earth combines with the fixed air of the alkali, and falls to the bottom. This powder, well washed and dried, is pure chalk, or calcareous earth united with fixed air. This last may be driven off by fire, and will leave the pure calcareous earth disengaged.

Calcareous earth requires about six hundred and eighty times its weight of water to dissolve it at the temperature of 60° , to which it gives a pungent taste. This water, called lime-water, acquires a white crust on the surface, by exposure to the atmosphere, which breaks and falls to the bottom, another crust forming soon after, and so on till the

whole of the lime is precipitated. The precipitate is chalk, or mild calcareous earth; whence the process may be easily explained. For chalk is scarcely, if at all, soluble in water: and the lime contained in the water being converted into chalk, by the accession of fixed air from the atmosphere, becomes an insoluble crust, that falls at intervals, as its quantity becomes too great to be supported at the surface.

- A This earth is soluble in all acids. It is infusible in every degree of heat yet obtained, except that of the famous lens of PARKER, in London, which produced a slight beginning of fusion. Yet it will melt in a more moderate heat, if mixed with other earths, of which it then appears to be the flux or solvent.
- B The specimens of calcareous earth are very many. Lime-stone, chalk, many kinds of marble, and almost every one of the numerous varieties of spars, whether transparent or opaque, consist of this earth combined either with the aerial or some other acid. Aerated calcareous earth may be known to predominate in any mineral, when it froths on the application of an acid.
- C Terra ponderosa, or ponderous earth, is not met with in abundance. The commonest specimens are the ponderous spar, or marmor metallicum, so called from its great weight, best known to our English miners by the name of cawk. It is met with opaque, white, grey or yellowish, either irregularly shaped, or in a singular form, resembling

bling convex lenses, set edgewise into the mass it adheres to. The transparent specimens are prismatic, and of considerable hardness. All these consist of ponderous earth, combined with the vitriolic acid.

Ponderous earth, combined with the aerial acid, has been found in Lancashire, and elsewhere. It resembles alum, but is of a striated texture, and its specific gravity is 4.331.

If the ponderous spar, or ponderous earth combined with the vitriolic acid, be exposed to a strong red heat, for about two hours, with near twice its weight of fixed alkali, the acid quits the earth to combine with this last, forming a neutral salt, which may be washed away, and leaves the earth combined with fixed air and water. The fixed air may be expelled by heat.

Pure ponderous earth, thus obtained, is soluble in about nine hundred times its weight of water. This water resembles lime-water in taste, and deposits its earth, by exposure to the air, in the same manner.

The properties of ponderous and calcareous earth agree in many respects; but in others they differ so much, as clearly to shew that they are not one and the same earth, as has been suspected*.

* See Bergman's Works, Kirwan's Mineralogy, and Withering on the terra ponderosa acrata, in Phil. Transf. for 1784.

- H Magnesia,* or magnesian earth, enters into the composition of some earthy substances, the chief of which are steatites, soap-rock, French chalk, asbestos, and talk. It is in the sea-water in great quantities, combined either with the marine or vitriolic acids. Epsom salt is a combination of the vitriolic acid with magnesia. If this be dissolved in water, and mild volatile alkali added, the magnesia is precipitated in combination with the fixed air, while the alkali unites with the vitriolic acid. The magnesia thus obtained, contains one fourth of its weight in fixed air, and about the same quantity of water. Both are driven off by fire, by which the magnesia is rendered pure, and has somewhat less than half the weight it possessed in its former mild state.
- I Clay or argillaceous earth, is found every where in great quantities, but in the native specimens it is always mixed with a considerable quantity of other earths. Alum is a salt, consisting of argillaceous earth, combined with the vitriolic acid. If it be dissolved in water, and the mild volatile alkali added, this last unites with the acid while the earth is precipitated, combined with a small proportion of the aerial acid.
- K Argillaceous earth imbibes water strongly, but is scarcely soluble therein. When sufficiently divided, it forms a tenacious mass with water, so as to admit of being moulded into various forms. It contracts very much by heat, and acquires a flinty

flinty hardness by baking, which does not then suffer any alteration from water; though its original softness and tenacity may be again restored by solution in acids, and precipitation.

This earth, which is so useful in the arts, has been applied*, with great success to the admeasurement of the higher degrees of heat. For as the expansion of the mercury, in a common thermometer, indicates the successive augmentations of temperature, so the contractions of the volume of a small brick of clay, by exposure to ignition, are found to be greater, the more violent the heat. By the help of which property we are in possession of an invaluable method of measuring and comparing those high temperatures,

Siliceous earth, which is also called crystalline, or vitrifiable earth, abounds in many substances. Crystal is one of the purest specimens. Extreme hardness is most commonly a characteristic of siliceous earths, so that stones, in which it predominates, will strike fire with steel, or at least will scratch its surface, however highly tempered.

To procure siliceous earth in a pure state, clear crystals, or quartz, must be reduced into powder, and melted with four times its weight of fixed alkali. The compound is then to be dissolved in water, and the vitriolic acid added in considerable quantity. The alkali and acid unite together, forming a salt that remains in solution: if

* By J. Wedgwood, Esq. See the Phil. Transf.

there be any other kind of earth present, it will likewise combine with the superfluous acid. But the siliceous earth being disengaged, falls to the bottom in a subtile powder, which must be cleared of the saline liquor by decantation, and repeated washing with pure water.

- O This earth is acted on by no acid but the acid of spar, or fluor. Fixed alkalis dissolve it, either in the dry or moist way. Like the other earths, it is not fusible without addition by any heat yet obtained.
- P Though the simple earths are all infusible alone, yet they may be fused by mixture with each other. The calcareous earth is found to act as a menstruum in dissolving other earths by fusion; and when it has once acted on any earth, a compound menstruum is formed, which is still more efficacious on other earths. Hence it is that equal parts of any three of the simple earths may be fused into glass, provided calcareous earth be one of the number.

C H A P. VIII.

THE GENERAL PROPERTIES OF COMBUSTIBLE
BODIES.

COMBUSTIBILITY was formerly supposed to constitute a distinct and essential character of bodies; and it still continues to possess sufficient importance with regard to the great and obvious changes in the universe to be admitted as a criterion of arrangement. All bodies are either combustible or incombustible, but it is highly probable that this difference arises merely from the latter having undergone the process of combustion or combination with vital air. Whether this general notion be admitted or not is however of less consequence in our deductions from existing and known facts. The bodies which are capable of undergoing combustion are not numerous. Most of them are acidifiable, and perhaps they might all prove so if we could acquire the means of completely burning them.

If we overlook the theory of Phlogiston for want of sufficient proof of its validity, we shall be necessarily led to consider those combustible substances as simple, which we have not hitherto been able to decompose after they have been burned by any reduction capable of shewing that they are convertible into substances different from the original

ginal body, and the vital air employed in burning it. But we must not at the same time overlook the circumstance, that in many instances respecting these fundamental enquiries, much of reasoning and no small quantity of incomplete deduction necessarily mixes itself in the attempts which philosophers make merely to ascertain the bare matter of fact, in experiments where weight and measure can scarcely be applied, and in most instances certainly cannot. Under these limitations which the cautious and unbiassed spirit which ought to prevail in our researches necessarily dictates, we proceed to enumerate the following as simple combustible substances.

Light inflammable air, called Hydrogen by the Anti-Phlogistians, is an inflammable substance which has never been exhibited alone but in the state of permanent elasticity. In this state it is much lighter than the air of the atmosphere. It is affirmed that the purest kind is seventeen times as light. Whether it produces any acid by combustion has not been incontrovertably ascertained; but there is little doubt that in a certain proportion it forms more water by combustion with pure vital air. Besides the inflammable air which is light, there are other kinds generally much more heavy and burning with a less luminous flame. From well instituted experiments it appears to be proved that these last fluids consist of the light inflammable air holding some other combustible matters in solution, such as sulphur, phosphorus, coaly

coaly matter, arsenic, and oil. The sulphureous solution is distinguished by the name of Hepatic air, because usually obtained from the combination of alkali and sulphur called Hepar. The phosphorated inflammable air, is called phosphoric air.

The diamond is a combustible substance which, on account of its great commercial value, has not been submitted to many experiments; it is formed in various parts of the Mogul empire, and also in the East Indian Islands, and the Braziis. It is usually of an octohedral form, though not unfrequently in round masses. The consent of mankind has stamped a prodigious value on the diamond; its great lustre, which seems to have been the property that originally attracted their notice, is owing to two causes. The first is, that being the hardest of all bodies, it takes and preserves a most exquisite polish, and the other is, that its refractive power is so much greater than that of any other medium, as to occasion all the light to be reflected (1, 270. A) which falls on any of its hinder surfaces at a greater angle of incidence than $24\frac{1}{4}$ degrees. Now at a less angle of incidence in glass on the internal surface than 41 degrees, the light will be transmitted; consequently if an artificial gem and a real diamond be compared, the light falling on each alike situated will be thrown back with its full glare from a diamond not only in all the cases wherein glass will reflect it, but likewise at all the angles between

41° and 24 $\frac{1}{4}$ °, while the glass suffering it to pass through will appear lifeless and dull. It is no wonder, therefore, that the effect of the diamond is so much greater.

No acid but the vitriolic has any effect on this gem, in which if Diamond powder be triturated, and evaporation carried on nearly to dryness, the acid grows black, and deposits pellicles that burn and are almost entirely consumed.

In a heat somewhat greater than is required to melt silver, diamond is entirely volatilized and consumed, producing a slight flame and leaving a foot behind. Neither the elastic nor fixed residues have been examined.

Sulphur or brimstone is an inflammable substance of a light yellow colour, either transparent or opaque, brittle, odorant; it enters into combination with oils, alkalis, earths, and metals, at a temperature not much greater than that of boiling water; it evaporates in the open air, and is decomposed, at the same time emitting a flame which by day has the appearance of a white fume, but in the dark is luminous, though its heat is so small that it may be suffered to play against the palm of the hand without much inconvenience. At a higher temperature it burns with a vivid blue flame, and is decomposed more rapidly, the acid taking the form of air of a most suffocating odour. This air called vitriolic acid air, unites with water if present, and forms the volatile vitriolic acid.

Sulphur

Sulphur is not decomposed, but sublimes without alteration if heated in a close vessel.

Phosphorus is a yellow or white transparent substance considerably resembling sulphur in its properties. Like sulphur it burns with two kinds of flame, but is much more inflammable. Fourcroy affirms that the slow temperature with a white luminous fume or flame, takes place in every temperature with which we are acquainted; and that the rapid combustion commences at 147° . I found that the phosphorus of urine prepared by Godfrey, which was probably less pure than that mentioned by Fourcroy, was not luminous in a freezing atmosphere at about 14° , but became luminous repeatedly as often as it was brought into a room at the temperature of 60° , and that the same phosphorus, placed in a vessel of water, burst into the rapid and strongly luminous combustion as soon as the water had acquired 160° of heat. In close vessels phosphorus sublimes entire by heat, provided respirable air be not present. The phosphoric acid is the product of the combustion of this substance. Phosphorus unites with sulphur, and with metals; is soluble in inflammable air, in oils, and in ardent spirit; combines with alkalis, and separates several of the metals from acids by reduction, at the same time that itself becomes acidified. Phosphorus, like sulphur, is found abundantly in the mineral kingdom. The greatest quantities are combined with calcareous earths.

Coaly matter, which is obtained most abundantly from vegetable substances by igniting them in such a situation as to prevent the access of air, at the same time that the volatile parts are at liberty to fly off, is considered as a simple substance, and has been distinguished by the name of Carbone. Charcoal contains a small proportion of saline matter and earth, but the combustible part takes fire when considerably heated in contact with vital air, and is by that means entirely converted into the acid which has been called fixed air. Carbone, or coal, appears to be soluble in alkalis and in inflammable air, it unites with several of the metals, particularly iron, with which it forms steel when the proportion of coal is extremely small, and plumbago, or blacklead, when the proportion is somewhat more than ten times that of the metal. It is a remarkable fact, that these two combustible substances, iron and coal, are very difficult of accension when thus combined, so that plumbago is an useful material for melting pots.

Though carbone or coal is not very readily combustible, its attraction for vital air is stronger than that of any other known substance, at temperatures above ignition. Hence it reduces metals and various acids to their original state of combustibility by attracting the vital air they may have combined with during calcination or acidification.

The last class of simple combustible bodies is occupied by the metals; these are distinguishable from all other bodies by their great specific gravity, and their

their opaque shining appearance. They are all fusible, crystallizable, and combustible, many of them burn with actual exhibition of flame, but none of them are so combustible as to maintain their own ignition in air no purer than that of our atmosphere. In vital air several of the metals ignited at one extremity, become completely burned throughout by the successive propagation and developement of the heat. When a metal has undergone combustion, its absolute weight is greater than before, though its specific gravity is less. In this state it no longer shines, but has the dull appearance of an earth, and is distinguished by the name of a calx. Some of the metals are acidifiable. Metallic calces are soluble in acids, and form salts. Such metals as are not calcinable to any sensible degree by mere heat with access of air, are called perfect metals, such as are calcinable by fire are called imperfect: metallic substances that may be extended by hammering, are called metals, in contradistinction to such as are more or less brittle, and are called semi-metals. All metallic substances conduct the electric matter with great facility.

Of the metals hitherto discovered, the perfect are gold, platina, silver, and mercury, or quicksilver; the imperfect are lead, copper, iron, and tin; the semi-metals are bismuth, nickel, regulus of arsenic, cobalt, zink, regulus of antimony, regulus of manganese, regulus of wolfram, and regulus of molybdena.

C H A P. IX.

OF THE VITRIOLIC ACID, AND COMBINATIONS
WHEREIN IT IS A PRINCIPAL PART.

- B** THE vitriolic acid, is so denominated because obtained from the salt called vitriol. It is usually obtained by combustion of sulphur. Sulphur is either found native in the neighbourhood of volcanoes, or united with earths or metals. One of
- c** the most common sulphureous compounds is the pyrites, or mundic. This consists usually of sulphur, iron, clay, and siliceous earth. It is generally of a yellow or greyish colour, of a globular or cubic shape, internally radiated, or sometimes lamellar. With the steel it strikes fire plentifully, whence its name is derived. If pyrites be exposed to heat in closed vessels, the sulphur sublimes; but in the open air it is decomposed by combustion, the quantity and combination of the principles left in the mass being by that means changed.
- D** The pyrites, by long exposure to the action of the air and moisture, suffer a remarkable change in their component parts. The sulphur, by a slow process analogous to combustion, becomes acidified, attracts water, and unites with the iron, forming vitriol, and with the clay, forming alum (164, 1). These may be obtained by solution in water; and a subsequent evaporation diminishes the quantity of the
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the solvent, so as to cause the salts to separate in the form of crystals.

If vitriol be exposed to distillation, the water that entered into the composition of the crystals rises, and afterwards the greatest part of the acid, with some excess of sulphur combined with it, leaving a brown mass in the retort, called colcothar. A second distillation, with less heat, separates the sulphureous acid, and leaves the dense concentrated vitriolic acid behind.

This process for obtaining the vitriolic acid is not now used, because a cheaper method has been contrived for procuring it immediately from sulphur. A quantity of sulphur and nitre grossly mixed, are placed in a vessel within a small chamber or room, lined with lead, and containing some few inches of water on its bottom. The sulphur is lighted, and the room closed. The nitre serves to maintain the combustion, by supplying pure air, and the vitriolic acid is thus volatilized in the form of air, which (169, w) combines with the water. To expedite this combination, it is said that steam of water is introduced into the closed room during the combustion. By a repetition of the process, the water becomes more and more acid. The redundant sulphur is either dissipated or acidified by exposure to air, and the acid is then concentrated by distilling off the superfluous water.

Vitriolic acid is dense, colourless, and has a stronger tendency to combination in most cases than every other acid. It may be so far deprived,

of water as to become concrete, but it attracts this fluid so powerfully as to deliquesce by exposure to the atmosphere in a short time, and does not cease to attract the humidity of the air till it has acquired more than six times its original weight. In cases where a certain quantity of air is required to be divested of its moisture, it may be performed by placing a cup, containing concentrated vitriolic acid, under the receiver that confines the air.

H. This acid, and, indeed, every other chemical principle, is best known by the phenomena it presents, and the combinations it produces when united to other bodies. The most common of these are here enumerated. The names are given according to the Nomenclature of Bergman, who converts the name of the acid in any combination into an adjective, which he applies to the base or other principle: such other synonyms are likewise added as are most commonly used by chemical or medical writers.

I. If the vitriolic acid be poured into a solution of the vegetable alkali, to saturation, which may be determined by a small quantity of the liquid producing no change of colour with the tincture of heliotropium (158, o) a neutral salt is formed that assumes the figure of crystals, as the water is diminished by evaporation. This is called vitriolated vegetable alkali, or vitriolated tartar, and contains thirty-one parts of acid, sixty-three of alkali, and six of water. It is not easy of solution in water, requiring sixteen times its weight to dissolve it in
the

the temperature of 60° ; but if the water be boiling, five parts are sufficient. Vitriolated tartar is used only in medicine.

The vitriolated mineral alkali, or Gläuber's salt, κ may be produced in the same manner, by making use of the mineral alkali instead of the vegetable. It contains fourteen parts of acid, twenty-two of alkali, and sixty-four of water, and resembles vitriolated tartar in many of its properties, but requires only three times its weight of water to dissolve it at the temperature of 60° . Great part of the water that enters into the formation of the crystals is dissipated by exposure for some time to the air, the salt gradually falling into a white powder or efflorescence.

Vitriolated volatile alkali, or vitriolic ammoniac, λ contains forty-two parts acid, forty of alkali, and eighteen of water.

Vitriolated lime, commonly called selenite, μ abounds in vast quantities in nature, and accordingly as its external appearance and texture differs, it is called gypsum, lapis specularis, alabaster. In the temperature of 60° it requires about five hundred times its weight of water to dissolve it, and from thence was formerly reckoned among the earths, though its component parts are thirty acid, thirty-two earth, and thirty-eight water. By exposure to heat a little below ignition, about twenty parts of its water are dissipated, at the same time that it falls into a powder, which is agitated by the vapours that escape in such a manner as to cause

the appearance of boiling. This powder is known in commerce by the name of plaster of Paris, and is chiefly used for making statues, and other articles that receive their figure from a mould; an use to which it is admirably adapted, by the speedy resumption of a solid form, when the water of crystallization is restored: for, if the powder be mixed with water, to the consistence of thin paste, it may be poured into a mould, and will run into all the strokes and cavities with the greatest facility; a few minutes after which, the water that maintained the state of fluidity, by mere mixture with the powder, combines intimately with it, and the whole mass becomes solid.

- N Vitriolated ponderous earth, or marmor metallicum, already described, (162, c) contains eighty-four parts of earth, thirteen of acid, and three of water; in the native specimens it is insoluble, or nearly so in water.
- O Vitriolated magnesia, or Epsom salt, contains twenty-four parts of acid, nineteen of earth, and fifty-seven of water. It effloresces like Glauber's salt, by exposure to the air, and requires about its own weight of water to dissolve it in the temperature of 60°.
- P Vitriolated clay, or alum, contains twenty-four parts of acid, eighteen of earth, and fifty-eight of water. Its crystals are usually covered with a slight efflorescence. In about fifteen times its weight of water, at the temperature of 60°, it is totally dissolved; but at higher degrees of heat it is soluble in a
very

very small quantity of that fluid. It is fused even by its own water of crystallization, and boils up into a frothy mass, which gradually dries into a white friable substance, called calcined alum. Calcined alum is, however, no otherwise changed than by the loss of its water, and may be reduced again into its original form by restoring it.

The combination of sulphur with a fixed alkali R may be made either in the dry way, by melting the two substances together, or in the moist way, by boiling sulphur in an alkaline lixivium, and evaporating the water. This last method is, however, seldom made use of. The liver of sulphur, so called from its colour, has a fetid smell, is soluble in water, and is very deliquescent.

The combination of sulphur and alkali attracts water from the atmosphere which it decomposes, the vital air of the water combines and acidifies the sulphur, while the inflammable air flies off in combination with another portion of the sulphur, which constitutes hepatic air, so that at length the alkali remains united only to the acid, forming either vitriolated tartar or Glauber's salt. The attraction exerted in this case between sulphur and alkali is much weaker than it would have been if the former had been acidified. For, if the liver of sulphur be dissolved in water, the alkali will be attracted and the sulphur precipitated, on the addition of an acid, whose elective attraction to the alkali is much less powerful than that of the vitriolic acid when perfectly formed.

- s The method of Stahl for producing sulphur, by what was called the direct combination of the vitriolic acid with the principle of inflammability, deserves to be mentioned in this place. Equal parts of vegetable fixed alkali, and vitriolated tartar, are fused in a crucible, after which somewhat less than one-fourth part of charcoal in powder is added, and the whole well mixed by stirring. The crucible is then covered, and a strong heat given for a very short time; after which it is taken from the fire, and the contents poured on a smooth stone, previously ground. This matter is not then found to differ in its essential properties from the liver of sulphur, and if dissolved in water, the sulphur may be precipitated by the addition of an acid. The theory of these facts was stated to be, that the phlogiston of the charcoal combined with the concentrated acid of the vitriolated tartar, and forms sulphur, which unites with the alkali in the same manner as other sulphur would have done if directly added. The modern theory is simply that the charcoal attracts the vital air, which is one of the component parts of the acid, and leaves the sulphur, which is the other component part.
- r The vitriolic acid, in combination with metallic calces, forms salts which have been denoted under the general name of vitriols. The three following only are known in commerce, or used in the arts.
- u Vitriolated iron, or martial vitriol, known vulgarly by the name of green copperas, contains,
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when recently crystallized, twenty parts of acid, twenty-five of iron, and fifty-five of water; but it effloresces by the loss of part of its water when exposed to the air. It requires six times its weight of water to dissolve it in the temperature of 60° . This salt is used in dying blacks, and in making ink for writing.

Vitriolated copper, or blue vitriol; of this v thirty parts in the hundred are acid, twenty-seven copper, and forty-three water. It is usually obtained from waters in Hungary, Sweden, or Ireland, in which it is naturally dissolved. It requires about four times its weight of water to dissolve it in the temperature of 60° . In some places w the waters naturally containing this salt are made to deposit the copper by exposing pieces of iron to their action. For the acid quits the copper, and forms martial vitriol, by uniting with the iron, which receives the necessary portion of vital air from the calx of copper, which consequently resumes its metallic state. The martial vitriol being soluble, remains in the water, while the copper falls to the bottom in a muddy or powdery form. If the solution, or water containing vitriolated copper, has no considerable excess of acid, eighty parts of iron will precipitate one hundred of copper. One of x the tests of the presence of vitriolated copper in a liquid consists in dipping a piece of clean bright iron therein, which becomes immediately covered with a thin coat of copper, in consequence of the

beginning of the process of transferring the acid from one metal to the other.

- v Vitriolated zink, vulgarly called white vitriol, or copperas, is of a white colour, and contains twenty-two parts of acid, twenty of zink, and fifty-eight of water. It is soluble in about twice its weight of water at the temperature of 60° .
- z If the concentrated vitriolic acid be heated with almost any inflammable substance, part of the vital air of the acid combines with and burns the substance, while another part of the acid having thus a redundant portion of sulphur, flies off in the form of vitriolic acid air. This air may be confined by mercury, but unites with water, forming the volatile vitriolic acid (172, F). Vitriolic acid air is fatal to animals.
- A In processes with some of the metals, especially iron and zink, the vitriolic acid, when properly diluted, is not decomposed, but the vital air for calcination of the metal is supplied by the water itself. The other principle of the water, namely inflammable air, therefore flies off instead of vitriolic acid air, which in this case is not extricated,

CHAP. X.

OF THE NITROUS ACID, AND COMBINATIONS WHEREIN IT IS A PRINCIPAL PART.

NEITHER the nitrous acid, nor any of the salts containing it, are ever found in considerable quantities in nature. This acid is obtained by the complete putrefaction of animal or vegetable substances; in which it is produced by the combination of the vital air of the atmosphere with phlogisticated air from the organized substances. Grounds frequently trodden by cattle, and impregnated with their excrements, or where vegetables rot, or in the vicinity of slaughter-houses, or burying-grounds, or other places exposed to putrid vapours, afford nitre after long exposure to the air. The earths that afford the best matrix for the reception and complete putrefaction of the vegetable or animal matter, are of the calcareous kind; and in some places artificial beds, compounded of putrescent matter and calcareous earth, are made with success for the production of nitre. If these beds contained much vegetable matter, a considerable portion of the salt obtained from them is true nitre, or the nitrous acid combined with the vegetable alkali; but if otherwise, the nitrous acid is, for the most part, combined with calcareous earth, and requires the addition of the vegetable alkali

to

to decompose it. With this intention wood-ashes, or pot-ash, is usually added in the process, which is as follows:

- D A number of large casks are prepared, with a cock at the bottom of each, and a quantity of straw within, to prevent its being stopped up. The nitrous earth is placed in these, together with wood-ashes, or pot-ash, either strewed at top, or stratified with the other matter. The vessels are then filled with hot water, which, after some time standing, is drawn off, and fresh water added repeatedly, so long as any salt can be extracted by this means. This washing of the earth is repeated, by passing the saline liquor through fresh parcels, till it is strongly impregnated. In this state it is conveyed to the boiler, and great part of the water evaporated by heat. A considerable proportion of common salt, which the water obtains from the earth, is deposited during the boiling, and taken out by means of a perforated ladle, while the nitre still remains in solution. For the quantity of nitre that can be held in solution by boiling water is much greater than of common salt; therefore, the common salt will begin to be thrown down at a much earlier period of the evaporation than the nitre, and a considerable portion of the former will be thus separated before any of the latter quits the solvent. When the liquor is sufficiently concentrated by boiling, which is known by trials made with small quantities taken out from time to time, it is conveyed

veyed into vessels where it cools, and much of the nitre is then found in a crystallized state.

The separation of the nitre from the common salt is much forwarded by another circumstance, wherein their solubilities differ. Nitre being dissolved to saturation in boiling water, will afford a large quantity of crystals by cooling; a proof that it is more soluble in hot than cold water: but common salt by the same treatment affords scarcely any. In the foregoing process it is found, that on this account the crystals formed by cooling consist almost entirely of nitre, the common salt remaining dissolved in the water, notwithstanding its change of temperature. And a repetition of the process serves to purify the nitre still more. With this intention, so much pure water is added to the nitrous crystals as is barely sufficient to dissolve them, and the evaporation by boiling is repeated. The crystals of nitre obtained by the second cooling are much purer than before, because the proportion of water to the common salt is greater, and consequently less will crystallize with the nitre. For nice purposes this boiling with fresh water is repeated four times.

If nitre be exposed to a strong heat in an earthen retort, a large quantity of air, much purer than that of the atmosphere, is produced, and the alkaline base is left in combination with the earth of the retort, which it dissolves. The weight of the air thus obtained, added to that of the alkaline base, amounts to the whole weight of the nitre made
use

H use of*. This fact is variously explained. The pure air is asserted by some to consist of the nitrous acid, deprived of water and phlogiston, and united to heat in a latent state; or of the nitrous acid perfectly saturated with phlogiston; or of the water that entered into the formation of the nitre, and is supposed to be, by some means, dephlogistigated; (148, M, N) or of a principle common to all acids. For the production of pure or dephlogistigated air, also takes place, when certain other salts which do not contain the nitrous acid are exposed to heat.

I A most intense degree of combustion takes place when nitre is brought into contact with any inflammable body, either of the two being previously made red hot. This continues either till the whole of the nitrous acid is dissipated, or the body consumed, and is evidently owing to the pure air produced, which maintains the combustion. In the detonation of nitre with combustible bodies, water is produced, formerly termed the clyffus of nitre, and most probably afforded by the combination of the inflammable air of the body consumed with the vital air of the nitre, (148, N).

K Gunpowder is usually composed of 75 parts nitre, sixteen charcoal, and nine sulphur, intimately blended together, by long pounding in wooden mortars, with a small quantity of water. Its effects are well known. Any part of a quantity of gunpowder being set on fire, the detonation begins, and

* Berthollet, in the Memoirs of the Royal Academy of Paris for the year 1781.

is propagated with amazing rapidity through the interstices of the grains. In consequence of which, a sudden and very powerful expansion of the materials takes place.

Nitre, or nitrated vegetable alkali, contains L thirty parts acid, sixty-three alkali, and seven water. It requires about seven times its weight of water to dissolve it in the temperature of 60° .

If concentrated vitriolic acid be poured a little at a time on pure nitre, in a tubulated retort, with a large receiver, taking care immediately to close the aperture, it will combine with the alkali, and the nitrous acid, called spirit of nitre in commerce, will rise in fumes that will become condensed in the receiver. After the spontaneous vapours have ceased, heat must be gradually applied, till nothing more will come over. Vitriolated tartar (17 $\frac{1}{2}$, 1) will remain in the retort, and if the acid in the receiver be added to pure vegetable alkali, it will again compose nitre.

This nitrous acid is of a yellow colour, and continually emits red suffocating fumes. These fumes arise from an excess of the base, which may be driven off, by hastily boiling the acid in an open vessel, when the acid becomes as clear as water. But the smallest addition of any inflammable matter, or even exposure to the sun's rays, will restore the former colour, and cause the acid to emit fumes as before.

Nitrous acid of the shops is seldom without a mixture of the marine acid, which it obtains from
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the sea-salt that crySTALLIZES with the nitre made use of, (18v, D). This may be separated by dissolving silver in a small quantity of the acid, and dropping gradually some of this solution into the acid required to be purified, as long as any cloudiness appears. For the marine acid combines with the silver, and forms a compound that precipitates to the bottom, leaving the nitrous acid pure.

P The red vapour which rises from the nitrous acid may be preserved in close vessels, without condensation by cold. It is called the aeriform nitrous acid. Water absorbs it, which becomes successively blue, green, and at last yellow, when it has received an increase of one-third of its bulk. This has been termed the phlogisticated nitrous acid.

Q Experiments with the aeriform nitrous acid are rendered difficult, by the circumstance of its acting on, and uniting with every fluid hitherto used in attempting to confine it.

R When nitrous acid is applied to combustible bodies, nitrous air is produced. This may be collected in water as well as quicksilver. Nitrous air exhibits no marks of acidity when properly prepared. Water will imbibe one-tenth of its bulk of this air.

S The mixture of nitrous with respirable air affords a remarkable and interesting appearance. Their union is attended with heat; a reddish brown cloud appears, and the sum of the spaces occupied by
T both airs becomes much smaller than before. It is found that their diminution is greater, the bet-

ter

ter adapted the respirable air is to the purposes of supporting animal life or combustion; and that nitrous acid is precipitated, and becomes dissolved by the water over which the operation is performed:

Dr. Priestley, whose discoveries respecting aeriform fluids have deservedly placed him in the highest rank of experimental philosophers, usually ascertains the purity of air by adding an equal volume of nitrous air to it, and expresses the same by writing in figures the space occupied by both after the diminution. Thus, if equal measures of common and nitrous air were diminished on mixture by $\frac{1}{3}$ of a measure, he says the measure of the test is 1.3; which number denotes the reduced bulk of the air which was originally 2. But when the purity of vital air is to be ascertained, he uses more nitrous air, a single measure not being sufficient. The purest vital air will receive the addition of three times its own bulk of nitrous air before the space it occupies is sensibly augmented.

The instruments used to determine the salubrity of air by this method are called eudiometers. In general, experiments may be made with a graduated tube *AB*, fig. 158, on which the space occupied by the air after its diminution may be read by means of the divisions.

If a mixture of two parts by measure of vital air obtained without the use of nitrous acid, and one of phlogisticated air or azote, or which is the same thing, five parts of vital and four of common
air,

air, be exposed to the action of the electric spark, in the upper part of a syphon in which it may be confined by mercury, and a small quantity of soap-lees or solution of pure vegetable alkali be admitted into the cavity which contains the air, an absorption will take place, and nitrous acid will be produced, as appears by the alkali being converted into true nitre. This is a slow operation, and requires the quantity of air in the syphon to be renewed very often to supply the absorption*. It has likewise been found that this acid is produced by exposing vital air for a long time to the exhalations of putrifying animal substances, together with calcareous earth, or any other proper base to receive and combine with it†. There can be little doubt but the putrid exhalations consisting chiefly of phlogificated air, it appears therefore that this substance bears the same relation to the nitrous acid, as sulphur does to the vitriolic. As sulphur by combustion, in which vital air is an indispensable requisite, becomes converted into vitriolic acid, so phlogificated air becomes converted into nitrous acid, though on account of its being less combustible, the red heat cannot be produced and kept up without the co-operation of electricity; and as sulphur when in contact with the pure air of

* For the detail of the particulars of this most curious experiment, consult Mr. Cavendish's papers in the Phil. Trans. Vol. 76, p. 372, and Vol. 78, p. 255.

† This is the discovery of Mr. Thouvenel. See his prize dissertation on the formation of Nitre.

atmosphere and with a base proper for combining with the vitriolic acid is converted into that acid by a slow combustion in the pyrites; so the like exposure of phlogisticated air in contact with calcareous earth to vital air, produces nitrous acid, though much more slowly, because the base is less combustible.

The nitrous acid, with the mineral alkali, forms w nitrated mineral alkali, or quadrangular nitre, which contains thirty parts of acid, sixty-three alkali, and seven water. Its properties are nearly the same as those of the common, or prismatic nitre, but it is less fit for making gunpowder, because it attracts humidity from the air. About three times its weight of water at the temperature of 60° are sufficient to hold it in solution.

Nitrated volatile alkali, or nitrous ammoniac, x contains forty-six parts acid, forty alkali, and fourteen water. This salt is remarkable for its property of detonating, without the contact of inflammable matter, when heated over the fire; which is one of the proofs that the volatile alkali contains inflammable matter.

Nitrated lime, or nitrous selenite, contains y thirty-three parts acid, thirty-two earth, and thirty-five water. It is deliquescent.

With ponderous earth the nitrous acid forms a z salt, whose crystals do not deliquesce.

Nitrated magnesia is a deliquescent salt, and a contains thirty-six parts of acid, twenty-seven of magnesia, and thirty-seven of water.

- B** Nitrated clay appears to be of very difficult solution in cold water, and may contain 153 parts of acid to 100 of earth*.
- C** The nitrous acid dissolves most metallic substances, part of the acid flying off in the form of nitrous air, and the rest in combination with the metallic calces, forming salt.
- D** The inflammation of oils, by the affusion of the nitrous acid, is a phenomenon that never fails to excite the astonishment of the beholders. All the oils obtained by distillation from vegetables, and distinguished by the name of essential oils, and also such other oils as are disposed to become thick and dry, by exposure to the air, are proper for this experiment. An ounce of the oil intended to be set on fire must be placed in a shallow vessel, and a bottle containing an ounce of the most concentrated nitrous acid must be fastened at the end of a pole, that the operator may be sufficiently distant from the inflammation. Two thirds of the acid being poured on the oil, excites a considerable ebullition; the oil grows black and thick, and sometimes inflames. But if this last circumstance does not happen in four or five seconds, the remainder of the acid must be poured where the mixture appears the most dry and black, and then the inflammation scarcely ever fails taking place.
- F** Fat oils may also be inflamed, if equal parts of the nitrous and vitriolic acids be first poured on them, and, when the ebullition is at the greatest, a portion of nitrous acid be poured on the driest part.

* Kirwan in Philos. Transf. for 1782.

The theory of this singular experiment is yet imperfect. There can be little doubt but the vital air of the nitrous acid (182, G) combining with the inflammable matter, produces the combustion (150. T, U). But the other circumstances relating to the capacities the new combinations in this process may severally have for heat, and on which the high temperature produced in a great measure depends, have not yet been sufficiently investigated. It is probably owing to these that essential oils are better adapted to this purpose than any other phlogistic bodies. The vitriolic acid may perhaps tend to conceal the nitrous acid in the experiment with fat oils, or perhaps its action on the oils may bring them nearer to the nature of essential oils, at least as far as it relates to this process.

C H A P. XI.

OF THE MARINE ACID, AND COMBINATIONS WHEREIN IT IS A PRINCIPAL PART.

THE marine acid is obtained from common salt. This salt, so universally used throughout the civilized parts of the world, is either dug out of the earth in large masses, called rock-salt, or obtained by evaporation from the waters of salt-springs, or of the sea. Sea-water usually contains between the twenty-fifth and thirtieth part of its weight

- of this salt, together with other magnesian or calcareous salts in much smaller quantities. In hot countries the water is evaporated so as to afford the salt in crystals, by mere exposure to the action of the sun and wind, in large receptacles, formed in the ground near the sea-side, and into which the water can be admitted at the tide of flood. In the south of France, and other parts of the world, they collect and dry the sea-sand, from which a strong brine is afterwards obtained, by passing such a quantity of water through it, as is merely sufficient to dissolve the salt that adheres to the grains. The intensity of cold in northern countries is also made use of for this purpose, where the sea-water being exposed to freeze, the ice is found to consist almost entirely of fresh water, and consequently, upon being taken out, leaves the brine much stronger. In these last-mentioned cases, as well as in more temperate climates, the crystals are obtained by boiling the brine in proper vessels over the fire.
- If the vitriolic acid be poured on sea-salt, it combines with the alkali (143, c) while the marine acid flies off in the form of marine acid air. This air is colourless, and permanently elastic when confined by mercury, but has a strong tendency to unite with water. When it escapes into the atmosphere, it has the appearance of white fumes, on account of the moisture it meets with, and unites to. The common marine acid consists of water impregnated

impregnated with this air, which it readily gives out on the application of heat.

In the method formerly used of procuring the marine acid by distillation from common salt with the vitriolic acid, much of the marine acid air was lost, for want of water to combine with. This is now remedied, by applying a second receiver *, containing water, into which a tube, proceeding from the upper part of the first receiver, is immersed. The marine acid air that escapes uncondensed from the first receiver combines with the water in the second, and converts it into strong marine acid.

The marine acid of the shops is of a light yellow colour, and continually emits suffocating fumes. The colour, however, is not essential to it, but arises from the solution of some impurities in the common process for making it.

Black manganese is the calx of a semimetal, (170, A) which contains a large portion of vital air, which it is disposed to give out. If four ounces of concentrated marine acid, with one ounce of this calx, be put into a tubulated retort, to which the apparatus of receivers used (190, Q.) in distilling the marine acid has been previously adapted, yellow vapours are abundantly disengaged, at first without the assistance of fire, and afterwards by means of heat. The water in the second receiver becomes impregnated with these fumes, of which, however, it absorbs a very small quantity. If the temperature be near freezing, the elastic fluid, after saturat-

* The invention of Mr. Woulfe.

ing the water, takes a concrete form, and gradually subsides to the bottom: but a very slight degree of warmth raises this substance in the form of bubbles, which endeavour to escape.

T As this vapour combines with water, and has likewise a powerful action on mercury, it has not been confined so as to retain its elastic state.

U It is found to consist of the marine acid, combined with an excess of vital air. It attacks combustible bodies with great vehemence, and dissolves all the metals directly, affording the same salts as the entire acid does, but without disengaging any inflammable air. It whitens vegetables and wax, and produces in many substances changes similar to such as arise from long exposure to air. When united to water, its taste is austere, but not acid; but it regains all the properties of the marine acid when again deprived of its excess of vital air by action upon combustible matter.

V A mixture of the nitrous and marine acids, or of the nitrous acid with common salt, or sal ammoniac, is called aqua-regia, from its property of dissolving gold. The power of this solvent on gold is supposed to consist in the marine acid, which is thought to be supplied with vital air from the nitrous, and is found alone in the crystals of salt produced in the combination of metallic calx and acid. There seems, however, to be some other circumstance concerned here; for it is not easy to say why the nitrous acid alone cannot calcine the gold, if its disposition to part with vital air, be
greater

greater than that of the aerated marine acid; and if this were not so, how could it afford the supposed excess to this last acid. But it is no uncommon appearance in chemistry for the properties of compounds to be very different from those of either of the component parts.

Salited mineral alkali, or common salt, contains w thirty-three parts acid, fifty alkali, and seventeen water. Its crystals are quadrangular, and do not deliquesce in the air.

Salited vegetable alkali, or salt of Sylvius, con- x tains thirty parts acid, sixty-three vegetable alkali, and seven water. It does not deliquesce in the air, and is soluble in about three times its weight of water.

Salited volatile alkali, or common sal-ammoniac, y contains fifty-two parts acid, forty volatile alkali, and eight water. It dissolves in about three and a half times its weight of water, at the temperature of 60°. By heat it sublimes unaltered, or nearly so.

Salited lime, or marine selenite, contains about forty-two parts acid, thirty-eight earth, and twenty water. It deliquesces in the air.

Salited ponderous earth is little known; its solu- z tion affords a valuable method of purifying the marine acid from the vitriolic, with which it is often adulterated. For, upon the addition of this to the marine acid under examination, the vitriolic acid, if present, seizes the ponderous earth; and forms the vitriolated ponderous earth, which being nearly

insoluble, falls to the bottom *. The exact quantity necessary to be added is known by trials on small portions of the acid.

- A Salited magnesia, or marine Epsom, is a deliquescent salt, found in greater quantity in the water of the sea than any other, except common salt.
- B Salited clay is a deliquescent salt, and may contain 174 parts acid, to 100 of earth.
- C The marine acid acts directly on, and combines with tin, lead, copper, iron, zinc, and bismuth, and with the other metals, by proper management, forming salts, possessed of various properties.

C H A P. XII.

CONCERNING THE ACIDS OF FLUOR, OF BORAX,
OF AMBER, AND OF PHOSPHORUS.

- D FUSIBLE spar or fluor, better known in England by the name of Derbyshire spar, consists of a peculiar acid, called the sparry acid, combined with calcareous earth and water. This spar is either transparent or opaque, of different colours, and generally has a cubic, rhomboidal, or polygonal figure. Most specimens, especially the coloured, have the property of becoming phosphorescent, or emitting light, when heated far below ignition, as may be done by laying them on a hot

* Withering in *Philos. Trans.* Part II. for 1784.

iron; but they lose this property by being made red-hot. It does not strike fire with steel, nor effervesce with acids. The calcareous earth is fifty-seven parts in the hundred, and the rest acid and water.

If an equal weight of concentrated pure colourless vitriolic acid be poured, by means of a tube, on pulverized fluor, in a retort, a decomposition of the fluor takes place with heat. The vitriolic acid seizes the calcareous earth, and the fluor acid escapes in the form of air, of a most penetrating smell, which may be confined by mercury, but unites with water in very considerable quantity. If the acid be wanted in a fluid state, it is necessary to adapt a receiver, containing water, about ten or twelve times the weight of the spar. This acid, especially when heated, and in the aerial form, dissolves, and retains siliceous earth, which it takes from the glass-vessels during the distillation, soon corroding them through, if they be not very thick. The fluor acid air deposits some of this earth by cooling; and the greatest part in the form of a white crust on the surface of water, when it combines with that fluid. In order to obtain the acid free from siliceous earth, it is convenient to use leaden vessels.

The saline combinations formed by uniting this acid with alkali, earths, or metallic calces, clearly shew that it is a peculiar acid, as different in its properties from all other acids as they are from each other.

Borax is a salt, imported from the East Indies, in

in the form of hexangular, or irregularly figured crystals, of a dull white, or greenish colour, and greasy to the touch. In this state it is called tincal. It is dug out of the earth in the kingdom of Thibet, in a crystallized state. The impurities are separated by solution, filtration, and crystallization.

K This salt requires about eighteen times its weight of water to dissolve it in the temperature of 60° . When heated, it swells up, loses its water of crystallization, and runs into a kind of glass, which may be again dissolved in water. It is chiefly used as a flux for soldering metals.

L The component parts of purified borax are, seventeen parts of mineral alkali, thirty-four of a peculiar acid called the acid of borax, or sedative salt, and forty-seven of water. In this combination not more than about five parts of the alkali are really saturated, for which reason borax in many cases acts as an alkali.

M If borax be dissolved to saturation in water, and the vitriolic acid be added, this last will combine with the alkali, and disengage the sedative salt, which will swim at the surface, in the form of white scales. The filtered liquor will yield vitriolated mineral alkali, or Glauber's salt. This acid is also obtained by sublimation; the alkaline base being separated by the previous addition of some stronger acid.

N The acid of borax requires fifty times its weight of water to hold it in solution. Its acid properties when uncombined are but weakly manifested. A moderate

moderate heat melts it with less intumescence than borax, but the glass so formed is again soluble in water. This fixed acid may be used for the same purpose as borax, and is a most useful flux in experiments to be made with the blow-pipe. It has been found uncombined in the waters of certain lakes in Tuscany.

Amber is a substance dug out of the earth more abundantly in the Prussian dominions than elsewhere. The most valuable specimens are of a clear transparent yellow. Its origin is probably from the vegetable kingdom, as it is almost always found in the neighbourhood of fossil wood. By distillation an acetous liquor, an oil, and a concrete acid, are obtained; which last may be somewhat purified by solution and crystallization. The combinations of this with alkalis, earths, or metals, denote it to be a peculiar acid.

Phosphorus (170, γ) till lately has been obtained by distillation from urine only, the water, and other more volatile parts, having been previously dissipated by heat in an open vessel. Towards the end of this process, which requires a strong fire of several hours continuance, the phosphorus comes over, and passes into the receiver, which must be half filled with water. But it is now known, that the phosphoric acid exists not only in all the solid parts of animals as well as in urine, but also in vegetables, and is found in the mineral kingdom, combined with lead, and with iron. The fixed parts of
the

the bones of animals is found to contain this acid, united to calcareous earth.

T If the bones of animals be burned in the fire till they have become white, they are in a proper state to afford the phosphoric acid. Three parts by weight of this matter in powder may be gradually added to two parts of concentrated vitriolic acid, and afterwards about five parts of water. This mixture must be left to digest for a day, water being added occasionally to supply what evaporates, at the end of which time more water must be plentifully added, and the liquor strained through a fine sieve. What remains in the sieve is gypsum, or vitriolated lime. The liquor, by evaporation to dryness, leaves a residue, consisting in a great measure of the phosphoric acid, which has been disengaged from its calcareous base by the vitriolic acid. This residue, urged by a strong heat, flows into a kind of glass of a whitish semiopaque appearance. It is not, however, necessary, for the making of phosphorus, to carry the evaporation farther than till the matter has acquired the consistence of syrup; which may be conveniently performed in a copper vessel.

U Equal parts of this liquid, and of charcoal in powder, mixed together, afford phosphorus by distillation in a good earthen retort (132, c). The receiver must be half filled with water, and must have a small hole pierced in its upper part, to let the elastic vapours escape; or, instead of a receiver, the neck of the retort may simply be plunged in water.

water contained in an open basin. When the retort is red-hot, the phosphorus will enter the receiver in drops, which ceasing, the whole apparatus must be suffered to cool. The phosphorus, which is in small masses, resembling reddish wax, or tallow, must be pressed together under water, particular care being taken that none remains sticking to the hands or under the nails, as a small particle, taking fire when brought into the air, in such a case, might be attended with very disagreeable consequences. It may be moulded into sticks, by putting the pieces under water into small upright tubes of glass, rather conical, and stopped at the lower end, and on heating the water, the phosphorus will melt and take the desired forms. The impurities that rise to the upper ends of the tubes, may be cut off when taken out of the water, which must not be done till all is cool; or, it may be had exceedingly pure by straining it through a leather bag immersed in hot water. But the best method of clearing phosphorus from the impurities of the first distillation is to distil it again with a very gentle heat.

To prevent the spontaneous combustion and acidification of phosphorus, it must be kept in a bottle with water sufficient to cover it.

The phosphoric acid may be had combined with water, by placing sticks of solid phosphorus in a glass funnel, inserted in the neck of a bottle containing water. A piece of glass tube, inserted in the neck of the funnel, will prevent the sticks from falling through. In this situation, if the temperature be moderately

moderately warm, the phosphorus will be gradually decomposed by the slow combustion (170, *r*), and afford its acid to the water. The acid thus obtained is contaminated with phosphorus, but becomes gradually less so by exposure to the air.

- x** Heat drives off the water from the phosphoric acid, so as to convert it into a solid transparent substance of an acid taste, which deliquesces by attracting the moisture of the atmosphere, and dissolves in water, at the same time producing heat.
- y** When urine is brought to the consistence of syrup by evaporation, a salt is obtained in crystals, called fusible salt of urine, or microcosmic salt, at first vitiated by an addition of extractive matter and common salt; but which may be purified by subsequent solution, filtration, and crystallization. This salt consists of the phosphoric acid, combined in part with the volatile alkali, and in part with the mineral alkali. If microcosmic salt be exposed to heat, the volatile alkali is driven off, while the phosphoric acid and mineral alkali remain fixed, and fuse together into a glass that affords phosphorus by distillation with charcoal (198, *v*).
- z** The mineral alkali in this glass prevents a considerable portion of the acid from being converted into phosphorus, forming with it a compound which has the properties of an acid. In this state it is convertible into glass by the action of heat, and effloresces by exposure to the atmosphere. It is soluble in less than twice its weight of hot water, and crystallizes by cooling. Bones afford it as well as urine.

C H A P. XIII.

OF THE ACIDS OF SUGAR, OF SORREL, OF LEMONS, OF BENZOIN, OF MILK, OF SUGAR OF MILK, OF ANTS, OF FAT, AND OF PRUSSIAN BLUE.

SUGAR is a saline substance, obtained from a most, if not all, nutritive vegetable substances, but most plentifully, or at least most usually, from the sugar-cane, which is cultivated in the warmer climates for that purpose. In the settlements of the Europeans the cane is crushed, by passing it between wooden rollers, which compress it to such a degree, that the vegetable fibres pass through, leaving most of the juices behind, which run into vessels, or troughs, properly placed to receive and conduct them to the boilers. The addition of alkaline ley and lime-water is necessary to the crystallization of the sugar, which takes place in consequence of the evaporation by boiling. Repeated solutions, and boiling in lime-water and ley, with the addition of oxes blood, or whites of eggs, for the purpose of separating the impurities in the form of skum, render the sugar more white and pure. The inspissated liquor, containing the sugar, is poured into conical earthen moulds, where it crystallizes, and the treacle is let out, by drawing a plug from an aperture in the
6 bottom.

bottom. A still greater degree of purification is obtained by spreading an argillaceous paste over the top of the sugar, great part of the remaining treacle being carried down by the moisture that slowly penetrates the mass.

- B A very slow cooling of a solution of sugar, in a heated room, causes it to shoot into large crystals, called sugar candy. In other cases the crystals are small and irregular.
- C The analysis of this salt is yet imperfect. By distillation alone it affords acid and an empyreumatic oil, leaving a considerable residue. The salt called acid of sugar, is, however, obtained by another process.
- D Let three ounces of strong nitrous acid, whose specific gravity is nearly 1.567, be mixed in a tubulated retort, with one ounce of the finest sugar in powder, to which, after the solution is completed, and the most phlogisticated part of the nitrous acid flown off, let a receiver be adapted, and the liquid gently boiled. As soon as it has acquired a dark brown colour, three ounces more of nitrous acid must be added, and the boiling continued till the coloured smoking acid has entirely disappeared. The liquor in the retort must then be poured out into a larger vessel, and will by cooling afford small quadrilateral crystals, which, collected and dried on bibulous paper, weigh 109 grains. The remaining lixivium boiled again in the retort, with two ounces of nitrous acid, affords 43 grains of crystals by cooling. Nitrous acid,
in

in the whole amounting to two ounces, being added, by small portions at a time, to the glutinous liquid remaining from the last crystals, and then evaporated to dryness, a saline mass is obtained, which contains about fifteen grains of crystals. All these products, but more particularly the last, require to be depurated by repeated solutions and crystallizations in pure water.

Neither the quantities nor the strength of the nitrous acid used in procuring these crystals need be nicely attended to; but the quantities obtained will be considerably diminished, if the boiling be continued after the vapours have disappeared.

It is concluded, that in this process the nitrous acid does not give more than afford vital air to combine with a vegetable basis existing in the sugar. The crystals are therefore called the acid of sugar, or saccharine acid. They have an exceedingly pungent taste, but excite an agreeable sensation on the tongue, when diluted with water. Vegetable blues, indigo excepted, are reddened by this acid, and it powerfully attacks and combines with alkalis, earths, and various metals, forming compounds that sufficiently distinguish it from every other acid. Boiling water dissolves its own weight of the crystals, but at 60° it will take up no more than half that quantity.

The saccharine acid effloresces in a heat greater than 60°. It may be sublimed by fire, though not without alteration. Repeated sublimation destroys

it; during which a great quantity of aerial acid and inflammable air are extricated.

- H The affinity of this acid to lime is greater than that of any other acid; the compound thus formed is intoluble in water, and can only be decomposed by fire. Hence the use of lime in causing sugar to crystallize. The native juice has a superabundance of acid that prevents crystallization; but this impediment is removed by the lime, which combining with it, is either carried off in the skum, I or sinks to the bottom. Hence also the saccharine acid affords one of the nicest and most certain tests to discover lime in waters.

- K Salt of sorrel consists of the vegetable alkali supersaturated with a peculiar acid. If the abundant acid be saturated with volatile alkali, and a nitrous solution of ponderous earth be added, decompositions and new combinations take place by double affinity. The nitrous acid seizes the volatile alkali, while the acid of sorrel, uniting with the ponderous earth, forms a compound, that, on account of its difficulty of solution, falls to the bottom. The sediment being washed, and placed in pure water, may be again decomposed by vitriolic acid, which forms marmor metallicum (175, N) with the earth. The disengaged acid of sorrel may be poured off. It is destructible by fire.

- L If the juice of lemon be boiled to the consistence of syrup, the vapors that fly off are not at all acid, but the residue will not afford crystals.

A quantity

A quantity of pulverised chalk being added to saturation to boiling lemon-juice, combines with the disengaged acid, and forms a compound, which, because very sparingly soluble in water, is precipitated. The saponaceous and mucilaginous matter of the juice remains in the supernatant fluid, and must be decanted from the precipitate, lukewarm water being repeatedly poured on this last till it comes off colourless. To decompose the precipitate, strong oil of vitriol, equal in weight to the chalk made use of, but diluted with ten times its bulk of water, must be added. The mixture, after a few minutes boiling, will contain the vitriolic acid united to the lime in the form of gypsum (174, M), and the acid of lemon disengaged in the water. Filtration or decantation will separate the gypsum, and the acid of lemon may be obtained in crystals by evaporating the water. The crystallization, however, will not take place, if, for want of strength, or a due quantity of vitriolic acid, there be left any lime in the solution. This may be known by adding a small quantity of vitriolic acid to the solution when evaporated to the consistence of thin syrup. If any precipitation takes place, more vitriolic acid must be added; and this last acid, if superfluous in quantity, will be found in the residuum after crystallization. The acid of lemons, M by digestion with spirit of wine and water, is converted into vinegar.

The saponaceous matter, decanted off after the addition of chalk to the lemon juice, may be con-

- o verted into acid of sugar by treatment with nitrous acid, but the acid of lemons cannot. It therefore appears, that lemons contain two acids, namely, the acid of lemons, disengaged, and the acid of sugar, in combination with oily or mucilaginous matter. Besides this, a small quantity of vegetable alkali is found, which shews itself by forming tartar, when the tartareous acid is dropped into lemon juice, and suffered to stand some days.
- P The fragrant resin, called benzoin, or benjamin, affords a concrete acid in the form of slender spiculæ, by sublimation, either in closed vessels, or by adapting a long paper-funnel to an earthen-pot, containing the benzoin in fusion over the fire. This acid may be obtained in a state of greater purity by careful boiling in powder with lime-water. The lime unites with the acid; and upon the addition of marine acid, the acid of benzoin which is scarcely soluble in cold water, falls to the bottom, while the muriated lime remains in solution. The acid of benzoin is destructible by heat, and when set on fire continues to burn with a bright yellow flame. It is readily soluble in ardent spirit, even in the cold.
- Q Milk in a short time grows sour and thick during summer. By filtration and evaporation the curds may be separated, and the whey is found to contain an essential salt, animal earth, or phosphorated lime (197, s), sugar of milk, a small portion of salited vegetable alkali (193, x), and some mucilaginous matter. The whey being evaporated to one eighth, for the more effectual separation
- tion

tion of the curd, and then strained; the acid is to be saturated with lime. The phosphorated lime is by this means precipitated, because deprived of the excess of acid that before rendered it soluble, but the acid of milk, forming a soluble compound with the lime, still remains suspended: the former is therefore separable by filtration. A solution of the acid of sugar being added, seizes the lime, (204, a), and leaves the acid of milk again uncombined. Spirit of wine dissolves this acid, but none of the other substances that remain in the whey. Evaporate the water, which would impede the action of the spirit by diluting it, and when the mass is of the consistence of honey, add the spirit. To this acid solution, after filtering, add pure water. Distillation will carry off the spirit, and leave in the retort pure acid of milk, dissolved in water. The acid of milk yields no crystals, and when evaporated to dryness, deliquesces again. It is destructible by fire, affording water, a weak acid, aerial acid, inflammable air, and coal. It exceeds vinegar in attractive power, and appears to be an incomplete vinegar, for want of a sufficient quantity of ardent spirit. For, if a small proportion of ardent R spirit be added to milk, the fermentation becomes more perfect, and vinegar is produced instead of this acid: and, in addition to this, the acid of milk, s with the addition of ardent spirit, is converted into vinegar after a month's digestion.

By evaporating whey to the consistence of syrup, T
a sweet salt is obtained in crystals, called sugar of
P 3 milk,

milk, which may be purified by subsequent solution and crystallization in water. In simple distillation its products are nearly the same as those of sugar; but when treated with nitrous acid ($2O_2$, D) it affords fifteen and one-half parts in the hundred of saccharine acid, and about twenty-three and a half of another acid, only found in sugar of milk. This last is in the form of a white powder. Sixty parts of boiling water dissolve one of this acid, and, on cooling, about one-fourth part of the powder separates in the form of very small crystals. It is decomposed by fire.

u When an ant-hill is stirred with a stick, the enraged insects emit an acid, which may be perceived to be such, both from its smell and taste. Water or ardent spirit, in which they are agitated, becomes acid. In the process with spirit, part of the acid arises in distillation with the spirit, but the greater part remains united with the phlegm in the retort. Fresh ants afford by distillation, without addition, near half their weight of acid. This, like all the acids of vegetables, is resolvable by heat into aerial acid, and inflammable air.

v The acid of fat is obtained by repeated distillations of that substance.

w Prussian blue is a beautiful pigment, well known in the arts. It is produced by the union of calx of iron, with a peculiar acid. The process for making it is as follows: Calcine equal parts of vegetable fixed alkali, and dried bullocks blood, till it ceases to emit either flame or smoke; then raise the fire

so as to give the mass a low red heat. Throw this matter red-hot into as many quarts of water as there were pounds of the original mixture, and boil it for half an hour. Decant this liquid, and wash the coaly residue with more water, till it comes off almost insipid. Add this last water to the former, and boil the whole till it is again reduced to the former number of quarts. This is the lixivium x sanguinis, or prussian alkali; which, if added in proper quantity to a solution of iron, precipitates it partly in the form of a calx, and partly in the form of prussian blue. The marine acid being poured on this precipitate afteredulcoration, dissolves the calx, and leaves the prussian blue much purer. The method of combining the alkali with the prussian acid by calcination does not saturate the whole; for which reason part of the iron is thrown down in a calciform state by that portion of the alkali which affords no prussian acid. But for v chemical purposes the prussian ley is produced by boiling the alkali in prussian blue ready formed. The calx of iron is thus deprived of the prussian acid by the alkali, to which it has a greater affinity, and which it only quits when there is another acid present to unite with the alkali, as in the just mentioned instance of the solution of iron, where a double affinity takes place. The prussian alkali z prepared in either way contains some iron. It can be had pure in no other way than by directly combining the pure prussian acid with a pure alkali.

- A Prussian alkali, boiled in a retort, with weak vitriolic acid, emits the prussian acid in an aerial inflammable form, which may be absorbed by water placed in the receiver. But as a portion of vitriolic acid comes over likewise, a second distillation is necessary, with the addition of chalk. The vitriolic acid by this means forming gypsum, is detained, while the prussian acid passes over totally, before one-fourth of the water is distilled off. It is not therefore necessary to continue the distillation beyond that period.
- B This acid is found to consist of aerial acid, or its base azotic air and inflammable air. If equal parts of pulverized charcoal and vegetable alkali be made red-hot for a quarter of an hour in a crucible, and some sal ammoniac, in small pieces, be then briskly stirred down into the mass, the ammoniacal vapours will soon cease. The ignited matter being thrown into water, affords a lixivium equal to the best that is made with blood.
- C A solution of the saturated prussian alkali is a valuable precipitant for discovering iron in liquids; no other substance forming prussian blue.

C H A P. XIV.

OF FERMENTATION, AND THE AERIAL TARTAROUS AND ACETOUS ACIDS.

WHEN animal or vegetable substances have n their organization by any means so far impaired as to be no longer capable of performing the offices to which they were adapted, life ceases, and, unless the temperature and dryness of the surrounding medium be such as either quickly to evaporate all the moisture, and more volatile parts, or to fix the whole mass by congelation, certain chemical processes take place spontaneously, by means of which both the fluid and solid parts lose their former arrangement and composition, at the same time that new combinations are formed. This act E of change is called fermentation, and is properly distinguished into three stages, namely, the vinous or spirituous, the acetous, and the putrefactive fermentations.

It is generally understood, that the vinous fer- F mentation does not take place except where sugar is present. The temperature most favourable to this fermentation is between thirty-six and ninety degrees; and the principal phenomena are these. The liquor becomes opaque, and warm. Aerial acid rises in minute bubbles from all parts. Mucilage is separated: part subsiding to the bottom, and

and part being carried to the top by the fixed air. For a certain time these appearances increase, but afterwards diminish, and at length totally cease; the fluid has then a pungent spirituous taste, instead of the sweetness it had before: its specific gravity is considerably less: and it affords
 H ardent spirit by distillation. The quantity of ardent spirit afforded by any fermented liquid is thought * to be in proportion to the diminution its specific gravity undergoes by fermentation; whether this be true or no, has not yet been proved by experiments; but it is highly probable that an attention to this diminution will afford the manufacturer some method of estimating the strength of beer, wine, and other liquors of the like nature.

r If the liquid in this state be confined in close vessels, the fermentation continues, but with extreme slowness, an acid salt, called tartar, is deposited, and the taste of the liquor becomes milder and more agreeable.

x But if the fermentative process be suffered to go on in open vessels, more especially if the temperature be raised to 90°, the second stage, or acetous fermentation, comes on, air is emitted, the mass grows warm, and mucilage is deposited: the intestine motion at length ceases, and the liquid becomes clear: it is then vinegar, and may be had purer by distillation. Ardent spirit is no

* Richardson on Brewing. London 1784.

longer found in the liquid, but the vinegar, when sufficiently concentrated, is itself inflammable.

The crude vinegar may be kept in well closed vessels; but if it be suffered to continue in the open vessels, it gradually loses its acidity, becomes viscid and foul; emits air; stinks; volatile alkali flies off; an earthy sediment is deposited, and the remaining liquid is mere water. This is the third stage.

The three stages of fermentation are never inverted in their order; that is to say, bodies that have passed the spirituous fermentation proceed to the acetous, and afterwards to the putrefactive process, and cannot again be subjected to either, after passing it. Bodies that begin to be destroyed by the acetous fermentation proceed afterwards to the putrefactive, but are incapable of the vinous process. And such bodies as immediately putrefy cannot be made to undergo either of the other stages. Some are of opinion that all vegetable or animal bodies, which are destroyed by spontaneous decomposition, undergo the complete fermentative process, but that the duration of one or more of the three stages is too short to admit of their being properly distinguished by observation.

The aerial acid, or fixed air, is not only produced in fermentation, but is found in mines, caverns, or wells, or combined with water or earths (155, F, G. 162, B), and is besides produced in various chemical processes. Its specific gravity being about one and a half time that of atmospheric air, causes it to lodge in the lower parts
of

of mines, where it is called choke damp. Its presence is first observed by the extinction or imperfect burning of the lights of the miners. Pure fixed air is instantly fatal to animals that breathe it. The atmosphere always contains some of this acid. Lime-water is the nicest test for discovering it; the lime being rendered mild and precipitated (161, 2). The immense quantity of this air, which is discharged by the vinous fermentation in breweries, affords opportunities of making the more obvious experiments in a very easy and striking manner. For the stratum of air that covers the fermenting liquor is about ten or twelve inches deep, or more, accordingly as the horizontal section of the vessel is higher above the surface of the liquor. Candles plunged in this body of air are instantly extinguished, and the smoke remaining in the fixed air renders its surface visible. Agitation throws it into waves. Water in a dish, immersed in the fixed air, and stirred briskly, soon receives a strong impregnation and lively taste. This aerial fluid may be dipped into, and brought out in a jar, like any other fluid which is denser than air, and does not readily mix with it. Nothing can be more singular than the experiments made by pouring this air out of one vessel into another. A candle becoming immediately extinct; an animal expiring in a few seconds, or an alkali crystallizing, when included in the vessel that receives the fixed air at the same time that the sight cannot perceive any thing that is poured.

The

The tartar that separates from wines during the slow fermentation (212, 1), consists of the vegetable alkali united to a peculiar acid. When purified by solution and crystallization, it is in commerce called cream of tartar. The acid in cream of tartar is more than sufficient to saturate the alkali. At a moderate temperature, this salt requires about one hundred and fifty parts of water for its solution. This small degree of solubility in tartar is wonderful, when it is considered that the acid, or the alkali singly, or even the neutral salt produced by perfect saturation of each, are very soluble.

The most convenient method of procuring the acid of tartar is, to add dry powdered chalk, by small portions at a time, to one hundred parts of the salt dissolved in boiling water, in a tin vessel. About twenty-eight parts will be required before the effervescence ceases. At this period the liquid must be decanted, and will afford, by evaporation, fifty parts of the perfectly neutral salt, called soluble tartar, or tartarized vegetable alkali. The remaining powder consists of tartarized lime, and weighs one hundred and three. On this washed powder let thirty parts of the strongest vitriolic acid, first diluted with two hundred and seventy parts of water, be gradually poured. After twelve hours digestion, the mixture being frequently stirred with a wooden spatula, the clear liquor may be poured off, and consists of the acid of tartar dissolved in water. The vitriolic acid remains combined
with

with the lime in the form of gypsum. To discover whether the solution contains any vitriolic acid, a drop or two of a weak solution of sugar of lead (which consists of the calx of lead united to vinegar) may be added. A white sediment falls of vitriolated lead, if that acid be present, but if not, of tartarized lead. It may be easily known by the effusion of strong vinegar on the precipitate, which of the two acids enter into its composition: for tartarized lead will disappear by solution, but vitriolated lead will not. If the gypseous residue contain any tartarized lime, it may be known by throwing a portion on hot coals, in which case the powder will grow black, and emit a smell of spirit of tartar. After filtration, and evaporation to the consistence of syrup, the solution of tartareous acid affords crystals. The quantity of acid weighs thirty-four, and the evaporation is carried to dryness.

v Certain vegetables, that have not undergone fermentation, likewise contain the tartareous acid.

v By digestion with water and ardent spirit, this acid is converted into vinegar. In the fire it grows black, and affords a spongy coal, which contracts much, and grows white by ignition. By distillation it affords phlegm, scarcely acid, with some oil, and leaves an earthy residue, neither acid nor alkaline. It is not convertible into saccharine acid by treatment with nitrous acid.

w Crude vinegar may be rendered much stronger by exposing it to the frost. The water freezes
 6 alone,

alone, and leaves the acid greatly concentrated; the water exceeding the acid that remains three or four times in quantity, or more, according to the intensity of the cold. This process renders the vinegar much less disposed to the putrid fermentation. For this last purpose, however, it may x be of importance to observe, that boiling for a short time, either prevents the putrid fermentation from coming on, or at least retards it very much. Common vinegar, after such boiling, will keep for several years*.

By distillation of crude vinegar the acid is obtained in that state of purity in which it is called the acetous acid. It is then no longer susceptible of the putrid fermentation. Like the other acids, it acts on alkalis, earths, and metals, with which it forms compounds distinctive of its own peculiar nature.

The acetous acid may be had very strong by z distillation from crystals of verdigris, which is a salt consisting of copper combined with the acetous acid. It is then called radical vinegar.

* Scheele's Essays. I do not, however, find it answer with our common beer vinegars.

C H A P. XV.

OF THE ALKALIS.

- A** NEITHER the vegetable fixed alkali, nor any of the salts containing it, are found in considerable quantity in the mineral kingdom. It
- B** is procured by burning vegetable substances in the open air, the salt being obtained from their ashes by elixivating them in water, and evaporating the clear solution to dryness. The crude or unrefined alkali, procured from wood-ashes, is called pot-ash. It is imported from the northern parts of Europe, where wood is cheap, and contains about half its weight of common salt in the state in which it is usually retailed in London. An addition made doubtless with a view to fraudulent profit. Pot-ash may be rendered purer by
- C** solution in water and boiling. As the water evaporates, the common salt will crystallize and subside, and the ley may be poured off at various times. The greater part of any salts it may contain are thus separated, after which the alkali may be dried, and placed on an inclined plane of glass, in a damp place. The purest part of the alkali will attract the humidity of the air, and run off in a liquid form into any receptacle placed for that purpose.
- D** There is not, however, any method sufficiently easy to render the fixed alkali of pot-ash pure enough

for nice chemical purposes, more especially as this salt may be had, without much trouble, from nitre or tartar. If the finest prismatic nitre be decomposed with charcoal (183, 1) the acid flies off, and the alkali remains in a mild state, and very pure. For this purpose the nitre must be made red hot, in a crucible much larger than is sufficient to contain it, and a small quantity of grossly powdered charcoal must be added. The inflammation instantly takes place, and continues till all the charcoal is consumed. More coal must then be added, and the same repeated till no farther detonation happens; care being taken to raise the heat towards the end of the process, so as to keep the alkali in fusion, lest it should cover and protect the remaining nitre from the contact of the coal. This is called fixed nitre, though there is no difference between the specimens of vegetable fixed alkali, when well prepared, whatever subject it may have been originally obtained from.

The vegetable alkali of tartar is very pure, and preferred by chemists to any other. The tartar is wrapped in wet brown paper, and the parcels are placed in beds or strata, alternately with beds of charcoal in a furnace. The whole is then set on fire, and the fire continued till the blackening smoke ceases to rise. If the heat be too intense, the alkali will melt, and mix with the impurities of the coal; but when the process is well conducted, the parcels of salt may be taken out entire. By elixivation in pure water, with filtra-

tion, evaporation, drying, and calcining, for a considerable time, with a low heat, the mild alkali is obtained very pure and white.

H Equal parts of tartar and grossly powdered nitre, detonated together, afford a very good vegetable alkali; the acid of the tartar abounding with sufficient combustible matter to decompose the nitre. When small quantities of this are prepared at once, it generally happens that the decomposition is not entirely completed, so that nitre and tartar remain mixed with the alkali; a circumstance of no consequence in the principal use to which this alkali is applied, namely, to bring earthy matters into fusion by fire. It is called white flux.

I For some operations this mixture of nitre and tartar are made use of without previous detonation. In this state it is called crude flux.

K Two parts of tartar, and one of nitre being detonated together, produce an alkali abounding with tartar and coaly matter. It is of use in such fusions as require the presence of charcoal as in the fusion or reduction of metals. It is called black or reducing flux.

L The vegetable alkali attracts the moisture of the air, and does not crystallize, unless combined with the aerial, or some other acid.

M The mineral fixed alkali exists in vast quantities in the common salt of the ocean, or salt springs, or in rock salt (189, H). It is sometimes found combined with the vitriolic acid in the form of Glauber's

ber's

ber's salt. (174, κ). On old walls it is found united to fixed air and water; in which state it is collected at the surface of the earth in many places in Asia and Africa. Borax likewise contains it (196, λ). The mineral alkali has not been procured from the native salts containing it, the aerial excepted, by any process sufficiently cheap. It is obtained by the incineration of certain plants of the kali kind, growing near the sea-side. The crude mineral alkali in commerce is called soda, or barillia. It contains several neutral salts in small proportions. Repeated solution and crystallization in water are used to purify it, as it is more soluble than the other salts that contaminate it, and consequently crystallizes last of all. For very nice purposes the purest common salt may be decomposed by melting with calx of lead; the acid combining with the lead, and leaving the alkali disengaged: or common salt may be decomposed by the addition of nitrous acid, which seizes the alkali, and forms quadrangular nitre. The nitre being deflagrated with charcoal, leaves the alkali disengaged. In either case, if common salt or nitre remain in the alkali, they will be separated by solution in water, and evaporation.

The mineral alkali is usually combined with enough of fixed air to render it crystallizable. Its crystals contain above half their weight of water, which flies off by exposure to the air, leaving the salt in a dry white powder. This alkali, when deprived of fixed air, will not crystallize; but, like

the vegetable alkali, attracts humidity from the air, and becomes fluid.

s The vegetable and mineral alkalis have a very great resemblance to each other in their properties, but the elective attraction of the former is, in general, the most powerful. Their combinations with acids have already been treated of. Their action on metals in the humid way is not considerable. The calces of several metals are soluble in alkalis by the dry method, as are likewise all the earths. Siliceous earths in particular, form, by fusion with alkalis, that beautiful product of human industry, glass. Caustic, or pure alkalis, unite with oily or fat substances, and form soap.

r The process for making glass is simple; but the practice is by no means easy. From one to two parts of alkali are mixed with two parts of vitrifiable earth, and the mixture calcined for a time in a heat not sufficient to convert it into glass. By this management great part of the more volatile matters, that might cause the melted mass to froth and swell, are dissipated. These calcined materials, called frit, are then melted into glass by a stronger heat; which, when formed into utensils, is gradually cooled in an oven. This is called annealing. The imperfections of glass are, opaque spots, bubbles, veins, or a coloured tinge. Some glass will change, or be corroded by the action of the air, or chemical menstrua. Such, in general, has too much alkali, or has not been held long enough in fusion.

Polish. Some will crack by small changes of temperature, by wiping, or by the slight scratches that an iron-instrument may make, or that may be produced by placing the utensil on a table where a particle or two of sand may casually lie. These faults commonly arise from a want of sufficient annealing, or the glass being suffered to grow too cold before it is carried to the annealing oven. The management of the heat is said to be of great importance in this art.

The art of making soap consists in depriving the alkali of the fixed air it may be combined with, and afterwards combining it with some oily substance, which, in the manufactories, is done by a gentle boiling. One part of quicklime, and two of soda, are boiled together for a short time, with twelve parts of water. The filtered lixivium is soap-lye, or a solution of caustic alkali, and may be concentrated by heat. If it be concentrated till its specific gravity is about 1.375, or, which is the same thing, till a phial that can contain an ounce of water will hold one ounce seven penny-weights and a half of the lye, the soap may be made without boiling. One part of this lye must be mixed with two of olive-oil in a glass or stone-ware vessel. The mixture being stirred from time to time with a wooden spatula, soon becomes thick and white, and in seven or eight days the combination is completed, and forms a very white and firm soap.

The lye in large manufactories is made no stronger w than to float a new-laid egg, when the workmen begin

to form the mixture. To a part of the lye diluted they add an equal weight of oil, which is set on a gentle fire, and agitated. When the mixture begins to unite, the rest of the lye is added, and the whole digested by a gentle heat till the soap is formed. If it be well made it is firm and white, not subject to become moist by exposure to the air, and completely mixes with water, without exhibiting any drops of oil on the surface. Trial is made of it, and the requisite alterations are obtained by the addition either of oil or alkali. At the end of the boiling common salt is thrown in. A twofold effect is hereby produced. The soap is separated, because not diffusible in salt-water; and it is rendered harder by the complete separation of vegetable alkali from it: for the vegetable alkali does not make a firm soap; and, as much of it as may be in the mixture, decomposes a portion of the common salt by stronger affinity to its acid. The alkali of the decomposed common salt, namely, the mineral, unites therefore with that portion of the oil which would otherwise have remained in combination with the vegetable alkali.

- x The cleansing property of soap is well known, and is to be attributed to its alkali, which will render a small portion of oily matter, beyond what it is already united to, diffusible in water. Soap is easily prevented from mixing with water by any salt, except alkalis, and is therefore no contemptible test of the purity of natural waters (149, 9).

Sal ammoniac, or salited volatile alkali, formerly y imported from Egypt, is now made in large quantities in Britain. The volatile alkali is obtained in an impure liquid state by distillation from foot or bones, or any other substance that affords it. To this the vitriolic acid is added. The vitriolic ammoniac (174, L) thus produced, is then decomposed by common salt, by double affinity; the vitriolic acid combining with the mineral alkali, and the marine acid with the volatile alkali. The liquor therefore contains Glauber's salt, and sal ammoniac, which are separated by crystallization, and the sal ammoniac is sublimed into cakes for sale. The cheapness of vitriolic acid and of common salt is the cause why they are made use of instead of the marine acid.

The volatile alkali cannot be had absolutely 2 disengaged from every other substance, except in the form of air. By distillation of sal ammoniac with lime, a solution of pure volatile alkali in water comes over (144, D) which cannot be rendered dry for want of sufficient fixity in the salt. If chalk be used instead of lime, the volatile alkali A receives more than its own weight of fixed air, and comes over in a concrete state much less pungent than in the other process, though not sufficiently neutralized to prevent its exhibiting its alkaline properties very strongly (160, w.)

Impure volatile alkali is purified by forming 2 sal ammoniac with the marine acid. Sal ammoniac becomes very pure by a few sublimations, and

the volatile alkali being recovered again by the process already described, is found to be one and the same salt, whatever may have been the subject that originally afforded it.

- c In the distillation of the caustic volatile alkali, (144, D) an aeriform fluid is extricated, which consists of the alkali, either pure or else combined with too small a quantity of water (145, D) to admit of condensation into the fluid state. It may be confined by quicksilver. With water it forms the caustic volatile alkali, from which heat again expels it: with fixed air it forms the concrete volatile alkali; and with marine acid air (190, O) it forms common sal ammoniac. When the strong caustic volatile alkali is distilled, it is therefore necessary to annex the pneumatic apparatus with water to receive the alkaline air (190, Q.)
- D The electric spark passed through alkaline air produces an impure inflammable air three times the bulk of the alkaline air, and when this is detonated with vital air, the residue is azotic air. Hence the volatile alkali is shewn, as well as from direct experiments of combination, to consist of inflammable air and azotic air.
- 2 The properties of volatile and fixed alkalis resemble each other, but the elective attraction of the latter is most prevalent. The volatile alkali has more direct action on metals and metallic calces than the fixed. In the dry way it cannot be exhibited. Caustic volatile alkali combines with oils, though difficultly. The saponaceous liquid, called eau de luce, is a preparation of this sort.

C H A P. XVI.

OF MINES AND METALS IN GENERAL.

THE internal parts of the earth, as far as the excavations made by natural causes, or by the industry of men, have given scope for observation, exhibit striking marks of the immense changes that have been produced by the chemical action of bodies on each other, during a course of ages far preceding all human record. It seems probable, that the loftiest mountains, which run in chains through the great continents, and are composed chiefly of granite, had their existence as such previous to that of the animals or vegetables on the earth. The same remark applies likewise to mountains of limestone, or marble of a granular texture, and is founded on the consideration, that the remains of those organized substances are never found in them. Other mountains, for the contrary reason, are evidently of posterior formation. Such as have their materials arranged in strata or beds, seem to have been formed by subsidence and crystallization in water. The planes thus formed, appear, from a variety of signs, to have been disjoined, broken, and thrown up into heaps by earthquakes, or similar convulsions of nature. Volcanos, or the eruption of subterraneous fires, have also contributed greatly to change the internal construction and
external

- L** external appearance of the globe we inhabit. There is no country or climate where visitages of these awful phenomena are not plentifully to be met with. Volcanic hills are often pyramidal, with a plain, or hollow cavity at top, and have one or more ridges proceeding from thence as a center. Strata of lava, and other volcanic products, abound in the vicinity, mostly beneath the surface, and are regularly disposed so as to point out the source
- M** from which they formerly issued. Metallic bodies are mostly found in the stratified mountains. The beds of these mountains being thrown up into an inclined position, appear to have been worn down by the long continued action of the atmospheric changes; so that strata, which in lower grounds are too deep for the miners to arrive at, are here rendered accessible.
- N** Such metallic combinations as are found in nature are called ores. The metal is said to be mineralized by the substance that is combined with it. It must, however, be observed, as an exception, that native metallic salts are not called ores.
- O** The chief mineralizers are sulphur, arsenic, or its acid, and fixed air. Metals are also found native or uncombined; but sparingly.
- P** There are entire mountains which consist of iron ore: other ores form but an inconsiderable part of the mountain in which they are found. Some ores run parallel to the stony strata, though very far from having that regularity of thickness
- those

those strata possess; others cross the strata in all directions. The last are called veins.

The stones wherein the ore is imbedded are called its matrix. These are not peculiarly appropriated to, any metal, but some stones more frequently accompany metals than others.

The art of extracting metals from ores in the small way is called assaying or essaying. The term is also applied to the separation of gold or silver from other metals, and procuring them alone. Ores may be assayed either by the dry or humid method. In the dry way the process is conducted nearly in the same method as when the metals are extracted in the large furnaces, and, generally speaking, discovers little more than the quantity of the metal contained in the ore. In the moist way, by skilful management, the quality and quantity of all the ingredients become known.

The process by fire for obtaining metals from their ores in large quantities for commercial purposes, is called smelting.

The operations for separating metals from ores are trituration, and washing in a stream of water, by which the lighter parts are carried off, while the heavier subside. This is of service when the metalliferous parts are considerably heavier than the rest. Roasting, by which sulphur, water, arsenic, vitriolic acid, or other volatile and useless substances are dissipated. Fusion or smelting with such a mixture of earths, or other matters as may facilitate the same, by which the superfluous part of
the

the ore is scorified, or melted into a slag or glass, sufficiently thin to allow the metalline particles to subside to the bottom of the furnace in a reguline state. In assays, combustible or coaly matters are used for fluxing the mass, that the metal may be reduced by depriving it of the vital air it may be combined with; but in large works the fuel generally answers that purpose.

It is obvious, that the trituration, washing and roasting, are not in all cases required; that in some cases the roasting must precede the trituration; and that the additions in the smelting require an attention to the supposed or known contents of the ore required to be fused. The previous examination of ores by the blow-pipe, (134, G) and more especially the humid analysis, are of great service, by indicating the proper additions to be made in smelting.

In the humid way the ore is finely powdered, and dissolved in such a menstruum as is adapted to take up either the whole or some of the parts conjectured, or by blow-pipe experiments known, to enter into its composition. The undissolved residue, if any, is subjected to trials by other menstrua. The parts in solution may be separated by the addition of precipitating matters, or by evaporating the solvent to dryness. The properties and weight of the precipitates indicate both the quality and quantity of each substance contained in the ore. This method of assaying, though incomparably more exact than the other, is not yet much practised, because the operations are slower, and require

an extensive application of the principles of the most enlightened chemistry*.

Metallic substances in their reguline state have a peculiar brilliancy and opacity (170, z.) Properties, undoubtedly owing to their great density, and their combustible nature. For the refractive power which bodies exert on light is found to be nearly as their densities (1. 262, A) excepting inflammable substances, and in these it is in a higher proportion. And, because the refraction and reflection of light arise from the same cause (1. 308, E) such bodies as refract most will also reflect the light most strongly. Opacity is a consequence of the reflection of light. White metals are very opaque. Gold-leaf, which is about $\frac{1}{111111}$ part of an inch thick, transmits light of a beautiful green; but silver-leaf, which is about the $\frac{1}{111111}$ of an inch thick, is opaque. Other metals have not been so much extended, and whether any of them are susceptible of it is not known.

Melted metals, like all other fluids, assume a symmetrical form in cooling (152, x.) The crystals are larger the slower the transition from the fluid to the solid state; and the specific gravities of

* See Bergman's Opuscula, and Kirwan's Mineralogy.

† This is the thickness deduced from the weight and surface of a book of gold, when the metal is so fine as to have but three grains of alloy in the ounce, and the workman extraordinarily skilful. Finer gold cannot be wrought in this way, because it is too soft to expand over the irregularities of the gold-beater's skins.

some, and, perhaps, all metals, are greatly affected in the same specimen (17, w) from this circumstance. Several metals are capable of having their crystals separated by agitation or pounding, just at the time of congelation; and have then a powdery or granular form. These, if struck with a hammer immediately after congelation, are broken, and exhibit the regular arrangement of their internal parts. Lead affords a remarkable instance of this.

- A Most metals will mix in all proportions with each other, though perhaps not uniformly, and may be afterwards separated by processes founded on the consideration of their various fusibility, solubility, or disposition to be calcined.
- B The specific gravities of these metallic compounds is scarcely ever such as would be mathematically deduced from their specific gravities of the metals made use of, on the supposition of their junction by simple contact.
- C The fusibility of these compounds is likewise such in several instances as would not be expected from the fusibility of the ingredients. In particular, a mixture of eight parts bismuth, five lead, and three tin, will melt even in a heat lower than is sufficient to cause water to boil.
- D The portion of baser or less valuable metal that is mixed with gold or silver, is called alloy.
- E The imperfect metals are calcined by heat with access of air: during this process they combine with the vital air of the atmosphere. The calces of molybdena, arsenic, and wolfram, are capable of uniting

uniting with a larger portion of vital air, and then become acid. Whence it is conjectured, that all metallic calces are of an acid nature.

Metallic calces are revived by strong heat in contact with combustible matter (152, w. 167, Q.) The black flux is very serviceable for this purpose; for, at the same time that its combustible part reduces the metal and its thin fusion favours its subsidence, the alkali promotes the work, by combining with the fixed air commonly contained in the calx.

A calx is heavier absolutely, but not specifically, than the regulus it was produced from.

The calces of metals are not only capable of revivification, but some of them appear to combine with so large a proportion of carbon or coally matter by the vapour of spirit of wine being passed over them when melted, as actually to become converted into a species of charcoal. Copper in particular is converted into a charcoal of more than twenty-six times its former weight, which may be burned in vital but not in common air *.

Metals are soluble in acids, but not in their reguline state. Such acids as cannot calcine a metal exposed to their action do not dissolve it, though they will take up the calx. During the solution of metals phlogiston escapes in the form of some kind of air that contains it. Metals too far calcined are not soluble.

When a metal is dissolved nearly to saturation in an acid, it will be precipitated in its reguline

* Priestley, VI. 207—211.

form by the addition of another metal, provided the attraction of the dissolved calx for vital air of the metal last added, together with its attraction for the acid be less powerful than the same attractions on the part of the metal which is added. The order of the precipitations of metals by each other is the same in all acids; a circumstance which shews that the attractions of the metals to vital air are more concerned in the effect than those of the acids for the calces. The order is, zink, iron, manganese, cobalt, nickel, lead, tin, copper, bismuth, antimony, arsenic, mercury, silver, gold, platinum: where any preceding in the list will precipitate any or all those which follow, but none of those that come before.

M Sulphur dissolves many metals, and the alkaline liver of sulphur dissolves them all except zink. For this reason, great care ought to be taken to roast sulphureous ores well, previous to assaying them with alkaline fluxes, as the sulphur, together with the alkali, forms this menstruum, and much of the regulus is retained.

N The imperfect metals are calcined by deflagration with nitre, and alkali in the same manner as any other phlogistic substance. Some of these, when sufficiently heated, burn, or are decomposed with flame, and most of them are rapidly burned by heating in vital air.

C H A P. XVII.

OF THE PERFECT METALS, GOLD, PLATINA, AND
SILVER.

THE perfect metals, gold, platina, and silver, o cannot be calcined in any sensible degree by mere heat, or deslagrated with nitre. When calcined by other methods, they may be reduced by heating, without the addition of any combustible matter.

Gold is a yellow metal of much greater specific p gravity than any other, except platina (17, w); directly soluble in aqua regia (192, v), and the aerated marine acid, and precipitable from these in its metallic form, by the solution of vitriol of iron. Vitriolic acid, distilled from manganese, also dissolves it. It has all the metallic characters (170, z) in the most perfect degree. When in fusion, it has a sea-green colour, which is also the colour of gold leaf by transmitted light.

Gold is mostly, if not always, found in its me- q tallic state. Some sands afford gold by simple washing, the heavy metallic particles subsiding soonest. But when embodied in earths, or stones, these are pulverized and boiled with one tenth of their weight of mercury, together with water. The mercury, after a certain time, absorbs the gold, and may be separated by distillation. Or other-

wise by heating the sand red-hot, and quenching in water several times, for the purpose of cracking and dividing it, and then melting the whole into glass with twice its weight of the calx of lead, called litharge. Charcoal being added, revives the litharge into lead, which subsides to the bottom, carrying the gold with it. If the lead, thus separated from the sand, be again converted into litharge by calcination, the gold will remain separate at the bottom of the test (130, x).

R This last operation, called testing, or cupellation when performed in the small way, is one of the best methods of separating the imperfect from the perfect metals. The mass of metals to be cupelled is put, together with lead, into a small shallow crucible of burned bones, called a cupel, and fused with a considerable heat, with access of air. The lead continually vitrifies, and carries all the imperfect metals with it. No litharge is produced in the small way, because the glass of lead is imbibed by the porous cupel. During the cupellation, the scoriae, running down on all sides from the metallic mass, produce an appearance called circulation, by which the operator judges that the process is going on well. When the metal is nearly pure, certain rainbow colours flash across the surface, which soon after appears very brilliant and clean. This is called the brightening, and shews that the cupellation is ended.

s If the cupelled mass contain more gold than silver, the gold may be dissolved by aqua regia,
and

and the silver will remain in a powdery form. If the silver prevail, pure nitrous acid will dissolve it, and leave the gold. It is found most advantageous to add pure silver, if required, to make the proportion of this metal to the gold as three to one. For in this case the quantity of silver is not so small as to be protected by the gold from the action of the menstruum, nor the gold so small as to fall into powder, when deserted by the silver. These processes are called parting.

If platina be supposed to be mixed with the gold, both may be dissolved in aqua regia, and the gold will be precipitated alone on the addition of martial vitriol. No other metal is precipitable from its solvent by martial vitriol but gold. The iron of the vitriol thus used becomes more calcined than before.

The precipitate of gold from its solvent by a volatile alkali, or by a fixed alkali, if the volatile alkali be present in the menstruum. (192, v), has a wonderful power of detonating, with a moderate heat, the gold being at the same time revived. The force of this explosion is not so great as that of gunpowder, if a judgment may be formed by burning it in a closed metallic vessel; but is much greater, if attention be paid to the prodigious noise it makes, and the laceration of the metallic plate it is burned upon. These contrary conclusions may be reconciled, either by supposing the force of aurum fulminans less than that of gunpowder, but that its velocity of expansion is greater at the beginning;

or otherwise, by supposing its force to be greater, but that, when inclosed and in contact with red-hot metal, the powder is decomposed in another way without explosion. Experiment must, however, determine. From various experiments upon this dangerous compound, it is ascertained that it consists of gold calcined and united to volatile alkali, and that the explosion is produced by the sudden combustion of the inflammable air of the alkali, with the vital air of the calx, while the azotic air, or other principle of the alkali, is extricated in the elastic state.

v Tin, either dissolved in aqua regia, or in substance, added to a solution of gold, precipitates the gold in the form of a beautiful purple powder, called the purple powder of Cassius, which is of use in enamels, as it gives a fine tinge to glass. The preparation of this powder, and the production of a clear ruby coloured glass, require peculiar management.

w Light distilled oils, and more particularly ether, take gold from its solvent, but no other metal. If the ether be left to evaporate, by imperfectly closing the phial, the gold falls in its metallic form, no longer soluble by the acid beneath. Ardent spirit, wine, or vinegar, mingle uniformly with solutions of gold, and separate it alone. These methods purify gold from all admixtures.

x Liver of sulphur combines with gold in the dry way into a mass, dissolvable in water.

y The imaginary value of gold probably originated
in

in its property of bearing the action of the air, and all other liquids commonly met with, without tarnishing or rusting; to which value, no doubt, its great and almost inimitable specific gravity has contributed.

The gold coins of Britain consist of eleven parts gold to one of copper. The alloy is required to give the necessary hardness.

Platina has been found hitherto only in the gold-^z mines in Peru. It comes over in the form of grains, intermixed with ferruginous sand and quartz. The grains that remain, after the most magnetical and earthy particles have been separated, are of a whiter colour than iron. These contain one third of their weight of iron, and have a specific gravity of 16 or 18. To purify ^a it, it must be repeatedly boiled in marine acid, till no more iron is separated, then washed, and dissolved in aqua regia; to this the Prussian alkali is to be added till it ceases to precipitate any iron; the clear solution being decanted off, the addition of pure sal ammoniac will throw down the platina, which may be fused in the most violent heat of a furnace. No other metal is precipitable by sal ammoniac.

Platina thus purified, is by much the heaviest ^a body in nature (17, w). It is very malleable, though considerably harder than either gold or silver. Its colour is not distinguishable from silver on the touchstone. When in the highest degree of purity it is not magnetical; but when its spe-

cific gravity is as low as 21.36, it still contains iron sufficient to render it susceptible of the magnetic touch, and obedient to a strong magnet*. It is soluble only in aqua regia, or the dephlogisticated marine acid, and is not acted on by sulphur. Mercury does not dissolve it. It withstands cupellation.

- c Platina unites with most of the other metals, so as to compose a uniform compound.
- d Silver is the whitest of all metals, soluble in moderately dilute nitrous acid, and in the vitriolic acid by the assistance of heat, but not directly in the marine acid, nor aqua regia. It is precipitable from either of the first mentioned acids by the addition of marine acid, which combines with its calx, and forms the nearly insoluble compound called luna cornea. Its malleability, compared with that of gold (231, γ), is nearly in proportion to its specific gravity.
- l Native silver is found in a great variety of forms, and imbedded in various earths. Some of the masses have been found of the weight of sixty pounds. The greatest quantity of this metal comes from Peru.
- f The ores of silver are very numerous. Sulphur, arsenic, marine acid, coal, iron, copper, antimony, are the substances that severally or collectively, in greater or less proportions, enter into their composition.

* See the section on magnetism.

The solution of silver, in the nitrous acid, affords nitrated silver, or lunar nitre, in small crystals. This salt detonates when heated with combustible matters; but fuses in a moderate heat, without addition, into a dark coloured mass, used by surgeons as a caustic, under the name of lapis infernalis.

Marine acid, or pure common salt, being added to a solution of silver, the silver falls down in combination with more than its weight of the marine acid. This compound melts in the fire, at a low red heat, and if cast into thin plates, is semi-transparent, and somewhat flexible like horn; whence its name *luna cornea*. If carefully prepared, it proves clear, and is supposed to have given rise to the notion of malleable glass. A greater heat does not expel the acid, but the whole concrete either rises in fumes, or passes through the pores of the vessel. As the marine acid throws down only silver, lead, and mercury, and the latter two of these are not present in silver that has passed the cupel (236, R) though a small quantity of copper may elude the scorification in that process, the silver which may be revived from *luna cornea* is purer than can be easily obtained by any other process. It is reducible by trituration with its own weight of fixed alkali and a little water, and afterwards melting the whole in a crucible, whose bottom is covered with mineral alkali, well pressed, the mass of *luna cornea* being also covered with the mineral alkali. This ma-

nagement is required in order that the reduction may take place before the volatilization comes on, which, in the usual method of reduction, would cause a considerable part of the silver to be lost.

- K The property of forming a luna cornea, or scarcely soluble compound, with marine acid, affords a good test for detecting the presence of small quantities of that acid, or unmetallic salt containing it, in waters. For by dropping the solution of silver in nitrous acid into such waters, a cloud, of a curd-like appearance, will be immediately formed by the combination of the calx
- L of silver with the marine acid, if present. This property also affords a method of purifying the nitrous acid (184; O).
- M Silver is not corroded by the action of the atmosphere; but is very apt to tarnish and grow black by exposure to sulphureous vapors.
- N Sulphur, and also the liver of sulphur, dissolve silver in the dry way.

The fulminating compound of volatile alkali with silver, exhibits one of the most astonishing instances of chemical detonation hitherto observed. Its properties were discovered by Berthollet*. Pure silver is dissolved in pale nitrous acid, and the calx precipitated by lime-water. After decantation of the fluid, the precipitate is exposed to the air for three days to dry, in which the inventor

* Journal de Philosophie, June 1788.

thinks the presence of light is requisite. This dried calx being agitated or stirred in a solution of caustic volatile alkali, assumes the form of a black powder which, when separated by decantation, and dried in the air, is the fulminating silver. The alkaline fluid likewise contains a portion of silver in solution which may be separated by evaporation, and cooling so far as to afford crystals, which also possess the detonating property.

Gunpowder and fulminating gold are not to be compared with this new product, for the first requires ignition, and the latter a perceptible degree of heat to produce detonation. But the slightest agitation or contact is sufficient to cause the silver to explode. When once obtained, it can no more be touched. Even the falling of a drop of water upon it produces the explosion. No attempts can therefore be made to enclose it in a vessel. None but metallic vessels can be used in the latter part of the process. The safety of the operator will be endangered if any quantity exceeding a grain of silver be used, and even in this case it is proper that his face should be defended by a mask, with apertures for the eyes covered with strong glass.

The theory of this detonation is the same as that of fulminating gold.

It is a valuable discovery of Mr. Kier *, that a mixture of strong vitriolic acid with the nitrous acid or nitre is a powerful solvent of silver, though it

* Phil. Trans. 1780, p. 367.

scarcely acts upon the metals. This is of considerable importance in the Birmingham manufacture where the silver in the cuttings of plated copper, is required to be separated from this last metal. For this purpose the pieces of metal are put into a glazed earthen pan, and a composition of eight or ten pounds of oil of vitriol, with one pound of nitre, is poured upon them, stirred about, and the action of the fluid assisted by a heat between 100° and 200° of Fahrenheit. When the liquor is nearly saturated, the silver is to be precipitated by common salt, which may be easily afterwards reduced, or otherwise the silver may be precipitated in its metallic state, by adding to the solution a few of the pieces of copper and a sufficient quantity of water, which enables the liquor to act on the copper. The theory of this effect still remains to be investigated.

- o Pure silver, like pure gold, is too soft to be used for ordinary purposes without alloy. In the British coinage fifteen parts of silver are alloyed with one of copper.

C H A P. XVIII.

OF THE IMPERFECT METALS; MERCURY, LEAD,
COPPER, IRON, AND TIN.

MERCURY or quicksilver is a metal of a bluish Q
white colour, not susceptible of rust, or tarnish,
by exposure to the air. Its fusibility is so great,
that it becomes fluid long before ice melts;
and its volatility is such, that it is driven off
by actual ebullition, at a temperature (127, R)
which the greater part of the other metals sus-
tain without melting. In its solid state it is mal-
leable. Its specific gravity (17, w) is greater
than any of the other metals, platina, gold, and
wolfram excepted. By a heat, nearly sufficient to
cause it to rise quickly in the vaporous form,
it is calcined, provided the access of atmosphe-
rical or pure air be allowed. This calx, impro- R
perly called precipitate per se, is of a red colour,
and resumes its metallic form by mere increase
of heat, at the same time that it gives out pure or
vital air.

Native mercury is frequently found, but per-
haps never free from metallic alloy. It is also
found mineralized, in the form of precipitate
per se, or combined with the vitriolic or marine
acids, or with sulphur. This last is called cinna-
bar. It is of various colours, from a yellowish to
a deep

a deep red, and is very ponderous. In close vessels it sublimes without any other alteration than being deprived of its impurities; in open vessels, with sufficient heat, it is decomposed. The mercury is obtained from it by distillation, with the addition of some substance that will combine with, and detain the sulphur; for which purpose iron, in small pieces, is commonly made use of. But if calcareous earth be mixed with or abound in the ore, no other addition is requisite. The paint called vermilion, is an artificial cinnabar, produced by combining mercury with sulphur by trituration and sublimation. One hundred parts of cinnabar contain eighty of mercury, and twenty of sulphur.

Mercury is judged to be pure when it is perfectly fluid, and runs in neat globules, without any pellicle on its surface, or without soiling a funnel of clean white paper, through which it may be poured by a very small aperture at bottom. If it leaves nothing behind after evaporation, its purity may be still more depended on. For purposes where the utmost purity is required, the mercury may be triturated with flowers of brimstone, till it disappears, by uniting with that substance in the form of a black powder, called ethiops mineral; with this may be mixed twice the quantity of quicklime or filings of iron, and the whole being submitted to distillation, the mercury will rise, and pass into the receiver. Dust, and other superficial impurities, are removed by pressing mercury through a leathern bag.

The

The concentrated vitriolic acid, by boiling *y* combines with mercury into a white mass, which, by the effusion of a sufficient quantity of hot water, becomes of a citron colour. It is scarcely at all soluble in water, and is known in medicine by the name of turbith mineral.

Nitrous acid dissolves mercury very readily, and *z* affords, by crystallization, a salt called mercurial nitre. If this salt, which is white, be exposed to heat, it becomes yellow, then orange coloured, and, lastly, red, in which state it is found not to differ from precipitate per se (243, *R.* 182, *G.*).

Vitriolic acid, added to a solution of mercury *A* in the nitrous acid, seizes the metallic calx, and falls to the bottom; forming the same combination as would have been produced by the direct solution of mercury in the vitriolic acid (245, *y*). The affusion of warm water converts it into turbith mineral.

The common marine acid does not dissolve *R* mercury, though it readily unites with it when sufficiently calcined by other means. Thus, when mercury is calcined by nitrous acid, in which it is dissolved, the marine acid being added, immediately seizes the calx, and forms a salt of difficult solubility, which falls to the bottom. It is observable, *c* in dissolving mercury in the nitrous acid, that the solution at the beginning is attended with the escape of nitrous air (185, *R.*), but that the mercury continues to be dissolved after the emission of air has ceased. The latter portion is therefore taken up
in

in its metallic state. If the marine acid be added to a solution of no greater quantity of mercury in nitrous acid, than could be dissolved with effervescence, the precipitate will be a salt of sparing solubility in water, and highly corrosive, known by the name of corrosive sublimate. But if the nitrous acid be loaded with as much mercury as it can take up, and marine acid be added, the precipitate will be mild, and scarcely at all soluble in water, and is then called mercurius dulcis, or calomel.

Corrosive sublimate has always, till lately, been made by sublimation. This is effected by a variety of methods, all which tend to combine the marine acid with the calx of mercury. If the white saline mass, produced by combining the vitriolic acid with mercury (245, y), be triturated with an equal weight of sea-salt, and exposed to heat in a cucurbit (129, x) the vitriolic acid quits the calx of mercury to combine with the alkali of the salt, while the marine acid thus disengaged unites with the mercurial calx, and forms the corrosive salt required. This is sublimed by the heat, in a white mass, crystallized in the form of needles.

Corrosive sublimate, triturated with mercury, absorbs or unites with a quantity about two-thirds of its own weight. Sublimation renders the union more perfect, and affords the mercurius dulcis of the shops.

The aerated marine acid directly attacks and calcines

calcines mercury, which it converts into corrosive sublimate.

Mercury combines with almost all metallic substances, and communicates to them more or less of its fusibility. When these metallic mixtures contain enough of mercury to render them soft in a mean temperature, they are called amalgams.

Lead is a white metal of a considerably blue tinge, not subject to be much corroded by exposure to air or water, though the brightness of its surface, when cut or scraped, soon goes off. It is very soft and flexible; not very tenacious, and consequently incapable of being drawn into fine wire. Under the hammer it is easily extended into thin plates, but its properties have not induced workmen to subject it to the same trials as gold, silver, and copper, and therefore its comparative malleability is not known. Its specific gravity is considerable. On the fire it melts long before ignition, at about the 540th degree of Fahrenheit's thermometer, at which period it begins to be calcined, if respirable air be present. In a strong red heat it boils and emits fumes. If melted lead be poured into a box, previously rubbed with chalk, to prevent adhesion, and continually agitated, it will concrete into separate grains, of considerable use in a variety of mechanical operations; or if it be poured into a mould, and turned out at the instant of cooling, a blow with the hammer will break the mass,

mass, and the symmetrical arrangement of the internal parts will be seen.

- L The ores of lead are most commonly found among earths of the calcareous or ponderous kind. Calciform lead-ores are either transparent or opaque spars, or pulverulent, or ochreous masses of a reddish or brown colour. They are reducible by fusion with combustible matters. Lead is also found mineralized by the vitriolic acid forming a white ponderous salt, soluble in water. Likewise combined with the phosphoric acid of a greenish colour. Sulphur is the usual mineralizer of lead. Of these the galena, or potters lead ore, is the most common. It is of a lead colour, but darker, and is for the most part formed in cubes of a moderate size, or grains of a cubical figure, with the cornets cut off; its texture being granular. When antimony enters into the composition, the texture is radiated or filamentous. There are also pyritous and red arsenical lead-ores, but the latter is very scarce. The sulphureous lead-ores contain silver. It is not indubitably established that native lead has ever been found.

- M By calcination, lead is converted into a dusky powder called plumbum ustum; a longer continued heat, with access of air, renders it white, yellow, and after some days, of a bright red, called minium, or red lead. The heat for this purpose must not exceed a certain degree. A greater heat converts the calx, by degrees, into a yellow

yellow flaky calx, called litharge; and by a moderately strong fire, it runs into a yellow transparent glass, which powerfully dissolves metallic calces (236, R); and unless combined with these, or earthy additions, corrodes and passes through common crucibles. This glass acts more strongly on siliceous than on argillaceous earths, and is a principal ingredient in fine white glass.

Vitriolic acid, by boiling, combines with lead into a saline mass. Nitrous acid unites with it into a crystallizable salt. The vitriolic acid, added to a solution of lead in the nitrous acid, seizes the calx, and falls to the bottom, forming the same compound as would have been produced by direct solution of lead. The marine acid in the same manner carries down the lead, and forms a combination called plumbum corneum, which is more soluble in water than luna cornea (241, H).

The marine acid acts directly on lead, by boiling.

The acetous acid dissolves lead and its calces. While lead, or ceruse, is made by rolling leaden plate spirally up, so as to leave the space of an inch between each coil, and placing them vertically in earthen pots, at the bottom of which is some good vinegar. The pots are to be covered and exposed for a length of time to a gentle heat in a sand bath, or by placing them in dung. The vapour of the vinegar attaches itself to the surface of the plates, and corrodes them, by that means reducing them into ceruse, which comes off in

flakes when the lead is uncoiled. The plates are thus treated repeatedly, till they are corroded through.

- Q The acid in ceruse is supersaturated. By solution of this compound in acetic acid, a crystallizable salt, called sugar of lead, is obtained, which is the same as would with less facility have been procured by dissolving lead directly in that acid.
- R Sulphur readily combines with lead, by the assistance of heat, and forms a compound, similar to the sulphureous lead ore.
- S Oils and fats have a strong action on lead and its calces. Litharge, or any of the other calces of lead are copiously and entirely soluble in oils by boiling, which are thereby rendered thicker, and more drying. Linseed oil, thus impregnated with litharge, is much used by painters, under the name of drying oil. Many of the plasters used in surgery have for their basis oil thickened by boiling with calx of lead.
- T Lead in its metallic state unites with most metals. It may be separated from copper by eliquation, or melting by a heat too low to fuse the copper. It altogether rejects iron.
- V Copper is a metal of a peculiar reddish brown colour; subject to tarnish; it grows black by long exposure to the air; and easily rusts by moisture. It is of very considerable hardness, tenacity, ductility, and malleability: and its elasticity is greater than that of any metal, except iron. From this
last

last property, masses of this metal emit a loud and lasting sound when struck, and that, more especially, when of a proper figure (68, w). At a degree of heat, far below ignition, the surface of a piece of polished copper becomes covered with various ranges of prismatic colours, the red of each order being nearest the end which has been most heated; an effect, which must doubtless be attributed to calcination, the stratum of calx being thickest where the heat has been greatest, and gradually thinner and thinner towards the colder part (1, 280). A greater degree of heat calcines this metal more rapidly, so that it contracts thin powdery scales on its surface, which may be easily rubbed off, the flame of the fuel becoming at the same time of a beautiful green or bluish colour. In a strong white heat, greater than is necessary to melt gold or silver, it melts and exhibits a bluish green colour.

Copper is sometimes found native. Its ores are either calciform, of a red, blue, or green colour, or sulphureous, with more or less of iron, arsenic, or zinc. It is also found mineralized by the vitriolic or marine acids (178, w). Copper is extracted from its ores by repeated fusions and roasting, by which the sulphur is driven off, and the baser metals scorified. Lead is an useful addition for depriving it of the last portions of sulphur. Silver is extracted from copper by eliquation (250, t) with lead, which carries the silver down with it. This process cannot however separate gold from

- copper. When the quantity of gold is suspected to be too small to be advantageously recovered by testing, (236, R) it may be extracted by pulverizing the sulphurated copper, sulphur being added if required, and grinding the mass with mercury, which amalgamates with the gold (235, Q).
- Y. Vitriolic acid, highly concentrated and boiling, dissolves copper, and by evaporation affords blue crystals (178, V) of vitriolated copper. By cementation of copper with sulphur, part of the mass becomes soluble in water, and affords the same salt.
- Z. Nitrous acid dissolves copper with great violence, and forms a deliquescent salt. The solution is green, as are also the crystals. This salt, dried and placed in a heat not much greater than the hand can bear, takes fire.
- A. Marine acid likewise dissolves this metal, and forms a deliquescent salt, which takes fire from a candle, and burns with a blue flame.
- B. Verdigris is made by stratifying copper plates with husks of grapes after the juice has been pressed out, the remaining acid forming this substance by corroding the metal. Verdigris dissolved in distilled vinegar becomes completely saturated with acid, and when crystallized, is improperly called distilled verdigris.
- D. Copper may be deprived of any acid by distillation, without any intermediate substance. The acetous acid thus recovered from crystals of verdigris, is called radical vinegar (247, 2).

When

When copper is separated from any acid by the addition of an alkali, in greater quantity than is sufficient for the purpose, the alkali dissolves part of the calx, and gives the liquor a blue colour.

Caustic volatile alkali dissolves copper if the access of respirable air be permitted. The solution is of a fine blue, and yields on evaporation, a saline mass of the same colour. It is observable that the alkaline liquid remains colourless while the air is prevented from communicating with its surface, but that the blue colour extends gradually from the surface downwards, when the vessel is opened. A circumstance well explained from the consideration that the air combines with the copper and renders it soluble.

Neutral salts, and also oils and fat substances, have a considerable action on copper.

Copper mixes with the other metals. The compositions most generally in use, in which copper enters as the principal part, are brass and bell-metal.

Brass is composed of copper and zink. According to the proportion of zink, the brass is of a yellower and paler colour than copper, and when the zink greatly abounds it is white. Brass is very ductile and malleable when cold, but brittle when hot. It is harder, more sonorous, and not so liable to rust as pure copper; and is also more fusible, and less subject to scorify in a moderate heat. These properties, added to the beauty of its colour,

lour, render it a very valuable material in the arts.

L The finest brass is not made by the fusion of copper and zink, but by the cementation of granulated copper with pulverized calamine and charcoal. The calamine, which is an ore containing zink in a calcined state, parts with its zink in the form of vapour when revived by the charcoal; and this volatile semi-metal combines with the copper. The process lasts eight or ten hours, or even some days, according to the quality of the calamine, at the end of which, by an increase of heat for a short time, the brass is fused into a mass at the bottom of the crucible. The quantity of zink in good brass, may be about one third.

M Bell-metal is composed of copper alloyed with tin. According to the proportion of tin the compound becomes paler than copper, and when the tin amounts to one third of the mass, it becomes of a very beautiful yellowish white. It is remarkable that zink, which is scarcely at all malleable, should unite with copper into the malleable compound brass; and on the contrary, the two malleable metals, tin and copper, compose bell-metal, which is so brittle, that it may be reduced to powder. The specific gravity of bell-metal is a circumstance equally singular; for in most proportions of the mixture it is about as heavy as the heaviest of the two metals, copper; and when the tin is about one third, its density is actually greater than

than that of copper*. The extreme hardness and sonorousness of this compound, together with its being less subject to alter by exposure to the vicissitudes of the air, than any other cheap metallic compound possessing the same properties, have recommended it in the fabrication of various utensils and articles; as cannon, bells, statues, &c. in the composition of which, other metals, however, are mixed in various proportions, according to the fancy or the experience of the artist.

The attention of the philosopher is more particularly directed to the mixture of copper and tin, on account of its being the substance of which the speculums of reflecting telescopes are made. For this purpose there is required a metal capable of an exquisite polish, hard enough to receive and retain a figure accurately suited to the regular reflection of light, and not subject to lose its polish or figure by the action of air and the vapours usually floating therein. Such a composition, it must be confessed, is still a desideratum; but the experiments and practice of the best artists shew, that pure copper alloyed with pure tin, affords a metal equal at least to most of the less simple mixtures given in books. As to the proportions, it is found that a small addition of tin renders the colour of copper whiter, and at the same time hardens it considerably. These effects are more and more prevalent while the dose of tin increases as far as a certain point. Fourteen ounces and a half of tin to

* Lewis on Newman, 1, 97.

two pounds of copper, is a good composition for
 o mirrors. One third part tin produces a whiter
 colour, but is too hard to be worked in the usual
 p methods of grinding. If the dose of tin be greatly
 increased, a softer metal of a bluish white colour
 is obtained, which bears and retains a good polish
 and figure, but does not seem equal to the yel-
 lowish white. Some care and attention are re-
 quired in casting mirrors, that they may not prove
 full of microscopic pores by the intermixture of
 calx. For this metal is easily reduced to a calx,
 and burns with a purple flame in a strong red heat.

q To prevent this, the copper must first be fused in
 a melting-pot, larger than sufficient to contain the
 whole, and whose upper part is filled with pul-
 verized charcoal, and the tin afterwards added;
 and when the mixture is completed, the whole
 must be suffered to cool, nearly to concretion, be-
 fore it is poured out. Or, which is still better, it
 may be poured out and again melted with a low heat,
 such as is merely sufficient for the purpose. Among
 various pieces cast out of the same fusion, the lat-
 ter proved always cleaner, better adapted to the
 mould, and of a more uniform texture when po-
 lished. The quantity of, about one fiftieth part of
 arsenic added at the last fusion greatly improves
 the density of the metal.

r Iron is a metal of a bluish white colour, more
 or less dark in various specimens, subject to rust
 by exposure to air and moisture. Its tenacity,
 ductility, and malleability are very great; and it
 exceeds

exceeds every other metal in elasticity and hardness. The appearance of prismatic colours (251, v) on its polished surface takes place long before ignition. It may be ignited by a quick succession of blows with a hammer. Struck with a flint it emits decrepitating ignited particles, such as can be obtained from no other metal by the same means. It is easily calcined by fire, but requires a most intense heat to fuse it when pure. During its decomposition by heat, it exhibits stronger marks of combustion than any other entire metal. It is even said *, that the blast of bellows will maintain its heat after it has been strongly ignited and taken out of the fire; and it is certain that the end of an iron wire being made red hot and dipped in a jar of vital air, will be entirely consumed by the successive combustion of its parts. Very fine shavings are consumed even in the common air. In a white heat, iron appears as if covered with a kind of varnish, and in this state two pieces applied together will adhere and may be perfectly united by forging. This operation, peculiar to iron, is called welding. Iron is thought to be the only substance in nature that has the property of becoming magnetical. Such other bodies as have that property, possess it in a very slight degree, and it may arise from iron contained in them, as far as experiments have yet unequivocally shewn.

Iron is more abundant and more universally diffused than any other metallic body. Few sands,

* By Dr. Hooke.

clays,

clays, stones, or waters of rivers, springs, rain, or snow are perfectly free from it. The parts of animal and vegetable substances have been also observed to contain it. Native malleable iron has been found, though rarely. Its ores are either purely calciform, as in ochres and hæmatites; or the calces are mixed chiefly with earths, as in spars, jasper, boles, basaltcs, micas, &c.; or the iron is mineralized with sulphur, as in pyrites, (171, c) with arsenic in the white pyrites, or with both; with bitumen in the coal ore; or combined with the vitriolic acid in native vitriol or vitriolic waters.

- T The ores of iron, after roasting, are smelted in furnaces of various magnitudes and forms. Some are thirty feet in height, their internal shape being nearly the frustum of a cone, whose larger base is uppermost. Near the bottom is an aperture, for the insertion of the pipe of large bellows, worked by water, or of other machines for producing a current of air, and also holes to be occasionally opened to permit the scoria and the metal to flow out, as the process may require. Charcoal or coke, with lighted brushwood, is first thrown in, and when the whole inside of the furnace has acquired a strong ignition, the ore is thrown in by small quantities at a time, with more of the fuel, and commonly a portion of lime stone, as a flux. The ore gradually subsides into the hottest part of the furnace, where it becomes fused, and the metallic particles revived by the coal pass through the scoria,

scoria, and possess the lower place. The quantity of fuel, the additions, and the heat must be regulated in order to obtain iron of a good quality; and this quality must likewise, in the first product, be necessarily different, according to the nature of the parts that compose the ore.

The best cast iron, or iron as much freed from heterogeneous matters as the usual process of smelting can effect it, is not at all malleable, and so hard, as perfectly to withstand the file. If this be kept in fusion for a considerable time, it boils, and much scoria is separated; and by repeated blows of a large hammer on the mass, when nearly at the melting heat, more extraneous matter is forced out, and it is rendered malleable. In this state it is much softer than before, and of a fibrous texture.

Steel is iron in an intermediate state between cast iron and iron which is soft, tough, and malleable. The iron run from some German ores is found to be a good steel, when forged only to a certain point. But steel is usually made by cementation from the best forged iron with matters chiefly of the inflammable kind. Two parts of pounded charcoal and one of wood ashes is esteemed a good cement. The iron bars are bedded separately, or apart from each other, in this cement, in a closed crucible, and kept in an equal red heat for eight or ten hours, at the end of which time they are found to be converted into steel. If the cementation be continued too long, the steel is brought to a state resembling cast iron, being rendered

rendered excessively brittle, incapable of being welded, and apt to crack and fly in forging: but on the contrary, cementation with absorbent earths or simple ignition long continued, reduces steel to the state of forged iron.

- x It is a valuable property of steel, that though it is sufficiently soft when gradually cooled, to be formed without difficulty into various tools and utensils, yet it may be afterwards rendered more or less hard, even to an extreme degree, by simply plunging it, when heated, into cold water. The hardness produced, is greater in proportion as the steel is hotter and the water colder. The colours that appear on the surface of steel slowly heated, are yellowish white, yellow, gold colour, purple, violet, deep blue, yellowish white, after which the ignition takes place. These signs direct the artist in reducing or tempering its hardness. Ignited steel quenched in water, proves excessively hard and brittle, but it may be reduced to the required degree of softness by heating it till it exhibits a known colour. Soft steel has a greater specific gravity than that which is hardened."

- y Crude iron, by cementation with animal ashes, may be brought up into a state resembling steel, and capable of being hardened by immersion in water; and a farther continuation of this process carries it beyond that point, so that it resembles forged iron. But this management is much less effectual than forging, probably because the impurities of the crude iron are not removed by it.

Tools and other articles wrought in forged iron, are often cemented with a composition of burned leather, horns, or the like substances for a short time, by which a very thin stratum of the external part is converted into steel, and is hardened by immersion in water. This is called case-hardening.

The chief differences in iron appear to depend a on the presence or absence of plumbago (169, v). When cast iron is dissolved in the vitriolic acid, a residue remains untouched, which is found to consist chiefly of plumbago, inflammable air being at the same time extricated (179, A). Steel in the same circumstances affords less plumbago and more inflammable air. Tough, malleable iron, similarly treated, leaves scarcely any residue, but gives out more inflammable air than either of the other kinds of iron. It is therefore seen that cast iron consists of the metal combined with plumbago, and perhaps calcined to such a degree as may be probably necessary (233, 1) in order to be capable of such an union. Steel is a more perfect iron, nearly as malleable in its soft state as forged iron; but in its hard state as brittle as the crude cast iron. Pure forged iron is the metal itself alone.

The iron obtained from various ores, or by various processes, is found to differ in its qualities in several other respects, the causes of which have not yet been sufficiently examined. In particular, the iron of certain ores, especially if the fusion in the smelting furnace has not been continued a sufficient time, has the quality of breaking in
pieces

pieces under the hammer when ignited. This is called red-short iron, and is supposed to contain arsenic.

- D Such iron as contains the phosphoric acid, is malleable when ignited and brittle when cold. This is called cold-short iron.
- E The vitriolic acid dissolves iron readily, and forms vitriol (178, v). The metal of this salt while in solution is farther calcined by the contact of air, and is by that means rendered less soluble in the acid (233, r). A quantity of ochreous matter or calx, therefore, gradually falls to the bottom in that case, and the liquor, as well as the crystals, obtained from it by evaporation, are paler.
- F Dilute nitrous acid dissolves iron and forms a saline combination incapable of crystallizing. Strong nitrous acid corrodes and calcines a considerable quantity of iron, which falls to the bottom.
- G Marine acid likewise dissolves iron, and forms an incrySTALLIZABLE compound.
- H The Prussian acid precipitates iron from its solutions in the form of Prussian blue (208, w).
- I Galls and other astringent vegetables precipitate iron from its solution in the form of a deep blue or purple secula, of so intense a colour as to appear black. The infusion of galls, and also the Prussian alkali, are tests of the presence of iron by virtue of the precipitates they throw down. Acids dissolve the black precipitate caused by
- x galls: alkalis convert it into a brown ochre. A
good

good and durable black ink may be made by the following directions: To two pints of water add three ounces of the dark coloured rough skinned Aleppo galls in gross powder, and of rasped logwood, green vitriol, and gum arabic, each an ounce. This mixture is to be put into a convenient vessel, and well shaken four or five times a day, for ten or twelve days, at the end of which time it will be fit for use; though it will improve by remaining longer on the ingredients. Vinegar instead of water makes a deeper coloured ink; but its action on pens soon spoils them.

Iron has a strong attraction to sulphur. If a *L* bar of iron be strongly ignited and a roll of sulphur be applied to the heated end, it will combine with the iron and form a more fusible mass, which will drop down. A vessel of water ought to be placed beneath, for the purpose of receiving and extinguishing it, as the fumes would otherwise be inconvenient to the operator.

If a mixture of five or six pounds of filings of *M* iron be moistened with a sufficient quantity of water to form a paste, it will in a certain time swell, become hot, melt, fume, and even take fire. The residuum furnishes martial vitriol. This process is similar to the decomposition of the martial pyrites (171, D; 150, T; 124, N). The water seems to be necessary to enable the acid to act on the iron.

Iron may be alloyed with all metals, except lead *N* and mercury. A coating of tin defends it from rusting

rusting by the action of the air, and other solvents, and is accordingly much used.

- o Tin is a metal of a yellowish white colour, not subject to rust, though its scraped or polished surface soon loses its brightness. It is not quite so soft as lead, has not much tenacity, and is the least heavy of any of the igne metals. Under the hammer it is beat into leaves of about the thousandth part of an inch in thickness, and might easily be beaten to less than half that thickness, if the purposes of trade required it. Long before ignition, it melts at about the 410th degree of Fahrenheit's thermometer, and by continuance of the heat, slowly calcines into a white powder. Tin, like lead, is brittle when heated almost to fusion, and being broken by the blow of a hammer, exhibits a grained or fibrous texture. It may also be granulated by agitation, at the time of its passing from a fluid to a solid state (247, x). Its calx resists fusion more than that of any other metal, and from that property it is useful to form an opaque white enamel, when mixed with pure glass in fusion.

- p The largest quantities of tin are found in the county of Cornwall in England. It is also found in Saxony, Bohemia, and the peninsula of Malacca in the East Indies, but rarely in any other countries in sufficient quantities to pay the charges of working. Native tin is seldom met with. The ores of tin are almost always calces of that metal in a crystallized form, bedded commonly in a fili-

aceous matrix. Such are the white tin spat, the opaque brown or black ore, the garnet ore, which abounds with iron, and the tin stone. These are all much heavier than any unmetallic substance. Tin has been found in Siberia, united with sulphur.

Tin ores, when impure, are cleansed from heterogeneous particles by pounding and washing (429, r). A slight previous roasting renders the stony admixtures more friable; and when arsenic is contained in the matrix, it is driven off by a strong heat, continued for a short time, the ore being frequently stirred to prevent its fusion. In the smelting, care is taken to add a larger quantity of charcoal than is commonly used in other fusions; and, to avoid a greater heat than is necessary to reduce the ore, in order that the loss of metal, which would otherwise happen by calcination, may be prevented as much as possible.

Concentrated vitriolic acid dissolves tin in a boiling heat. During the solution, vitriolic acid air escapes, and sulphur is formed in dark coloured particles, which are said to sublime in their proper form* in the neck of the retort.

Nitrous acid acts very powerfully on tin. To obtain a perfect solution, the metal must be added a very little at a time, and all heat avoided; for if much tin be put in at once, the corrosion takes place with great rapidity and heat, and the metal falls to the bottom in the form of

* Neumann.

a white calx, insoluble in acids (233. 1), and of difficult reduction. The salt, formed by the union of tin with the nitrous acid, burns and sparkles in a red heat.

T If crystals of cupreous nitre (252. 2) be grossly pulverized, moistened, and rolled up in tin-foil, the salt deliquesces, and the nitrous acid begins to act on the tin with heat, nitrous fumes are emitted, the cupreous nitre takes fire, and burns likewise the newly formed portion of nitrated tin.

W Marine acid dissolves tin with the assistance of heat, and affords crystals by evaporation. If corrosive sublimate be added to tin, divided by previous amalgamation with mercury, the marine acid combines with the tin, and comes over by distillation, in the form of a strong smoking liquid, which, if diluted with water, grows opaque, and deposits calx of tin.

V Aqua regia dissolves tin directly, and when loaded with that metal, has a gelatinous appearance. This solution is used by dyers for heightening the colours of cochineal, gum-lac, and some other red tinctures, from a crimson to a bright scarlet, in the dying of woollens.

W Tin combines with sulphur by fusion, and forms
 x a brittle mass, less fusible than pure tin. If the amalgam of tin, with half its weight of mercury, be set to sublime with sulphur and sal ammoniac, each equal in weight to the mercury, the whole being previously well mixed in powder, a sparkling gold coloured substance is obtained, which consists

consists of tin and sulphur, and is called aurum musivum. The process is thus explained: as the heat increases, the tin, by greater affinity, unites with the marine acid of the sal-ammoniac, and sets its volatile alkali at liberty, which flies off, together with a portion of the sulphur, in the form of an hepar. The salted tin rises by sublimation, and is found adhering to the sides of the vessel. The mercury, which was only added to divide the tin, combines with part of the sulphur, and forms cinabar, which also sublimates. And the remaining sulphur, with the remaining tin, forms the aurum musivum, which occupies the lower part of the vessel. It is used as a pigment.

Tin unites with all the metals. Clean iron plates, dipped in melted tin, become covered with a thin coating of that metal, and form a very useful material for making wholesome kitchen utensils, and other articles. In performing this business it is found necessary, either to dip the clean iron previously in a solution of sal-ammoniac, or to keep the surface of the tin covered with fat and pitch, in order that the apposition of the two metals may not be prevented by the calces that the contact of air might form on their surfaces. These plates, which possess the cleanliness of tin, added to the rigidity of iron, are much used. In England they are called tin plates.

Pewter is a compound metal, whose basis is tin. The best pewter consists of tin alloyed with a quantity not exceeding one twentieth of copper, or

other metallic bodies, as the experience of the workman has shewn to be most conducive to the improvement of its hardness and colour. The inferior sorts of pewter contain much lead, have a bluish colour, and are soft.

- A Useful compounds are made with tin, and a large proportion of copper (254, M).

C H A P. XIX.

OF THE SEMI-METALS, BISMUTH, NICKEL, REGULUS OF ARSENIC, COBALT, ZINK, REGULUS OF ANTIMONY, OF MANGANESE, OF WOLFRAM, AND OF MOLYBDENA.

- B BISMUTH is a yellowish or reddish white semi-metal, little subject to change in the air. It is somewhat harder than lead, and scarcely, if at all, malleable, being easily broken, and even reduced to powder by the hammer. The internal face, when broken, appears composed of large shining plates, disposed in a variety of positions. It melts at the 460th degree of Fahrenheit. Thin pieces are considerably sonorous.
- C This semi-metal is often found native. Its ores are either calciform or sulphureous.
- D Bismuth is scarcely soluble in the vitriolic acid, and still less in the marine. Nitrous acid, or aqua régia, dissolves it. The addition of pure water precipitates

precipitates its calx, and is the criterion by which bismuth is distinguished and purified from all other metals. This white calx, called magistery of bismuth, or Spanish white, is used as a paint for the complexion, which however it gradually impairs.

Most metallic matters unite with bismuth, and are rendered more fusible by the addition. It is used in making pewter, printers types, solder, &c. The great fusibility of the mixture of bismuth, tin, and lead (232, c), renders it of use in making collars for the axles of some mechanical instruments to run in.

Nickel is a semi-metal of a reddish white colour, of great hardness, scarcely yielding to the file, and of an uniform texture. It is very difficult to purify it, and is supposed, even when as pure as it has hitherto been obtained, to contain iron, as it is magnetical. It is malleable, and scarcely more fusible than pure iron.

The vitriolic and marine acids do not easily attack this semi-metal. The nitrous acid and aqua regia dissolve it readily. Its solutions are deep green.

Regulus of arsenic is of a bright yellowish white colour, subject to tarnish, and become black by exposure to air; very brittle, and of a lamellar texture. By heat it sublimes partly in the form of calx, and partly unaltered. The fumes have an offensive smell, resembling garlick, and are said to be dangerous.

- I The arsenic met with in commerce is brought chiefly from the cobalt works in Saxony, for making zaffre and smalt. The arsenic contained in great quantity in cobalt ores, is driven off by long torrefaction. These fumes pass into and adhere to the sides of a very long chimney, constructed for that purpose. Arsenic is a calx of the regulus; and contains no fixed air. It is so far in a saline state as to be soluble in eighty times its weight of water.
- K The regulus is obtained from this calx, either by quickly fusing it together with twice its weight of soft soap and an equal quantity of mineral alkali, pouring it out, when fused, into an hot iron cone; or by mixing it, in powder, with oil, and distilling the whole gradually to dryness. The regulus sublimes towards the end. This process is too offensive to be made but in the open air.
- L White arsenic previously divided by solution in boiling marine acid, is so far calcined by repeatedly pouring nitrous acid on it, and distilling it off, and at last raising the heat to ignition, that it becomes an acid, in the form of a concrete white mass, very soluble in water, and possessing peculiar properties. This is the arsenical acid.
- M The acetated marine acid (191, 5, 7) likewise affords vital air to the arsenical calx, and produces the arsenical acid *.

* These processes are amply described in Scheele's Chemical Essays. London, 1786.

The vitriolic acid dissolves the regulus of arsenic by boiling. The marine acid and aqua regia also dissolve it by heat. Nitrous acid calcines it (271, L).

Arsenic in any form is a strong poison. O

Cobalt is a semi-metal of a bluish grey colour, P of considerable hardness, and very brittle. When well purified it is nearly as infusible as iron. Its ores are either calciform, or it is mineralized with the vitriolic or arsenical acid. They mostly abound with arsenic, and contain bismuth, iron, or other metallic matters.

These ores have not been found in plenty, or Q at least worked to advantage, except in Saxony. They are valued for the beautiful blue they impart to glass, and are manufactured on the spot into zaffre and smalt. The first consists of the calx of cobalt simply mixed with pulverized flints, moistened and pressed into casks. The latter is the same calx fused into glass with vitrifiable earth and alkali, and reduced to a fine powder, by quenching in water and levigation, or rolling in a mill.

Cobalt is easily soluble in the nitrous acid or in R aqua regia, to which it imparts a red colour. The vitriolic acid scarcely acts on it, unless boiling and highly concentrated. The marine acid has no action on the regulus, but dissolves the calces.

Zink is a white semi-metal, not subject to rust in S the air, harder than either lead or tin, malleable in a certain degree and laminable, and so tough that a thin piece may be bent several times backward and

forward before it breaks. Its fracture exhibits shining facets. Some time before ignition it melts; when ignited it becomes covered with a white calx, and on the heat being raised and the surface of the metal uncovered, it burns with a very bright flame, at the same time that part of the calces are driven up in the form of a white smoke, which floats in the air.

- t The ore. of zink, are either calces, as the zink-spar, and calamine; or mineralized with sulphur, as in pseudo-galena or black jack, and blends of various colours. The sulphureous ores require torrefaction. Zink is obtained from its ores by distillation with charcoal, in closed vessels in a reverberatory furnace, their construction being peculiarly adapted to preserve this volatile and inflammable metal from being dissipated or calcined.
- u Zink is readily dissolved in acids. White vitriol (179, v) is the only saline combination of this metal found in commerce.
- v Sulphur has no action on this semi-metal: whence it is easily purified, by burning sulphur on its surface when in fusion. These two substances are united in ores by the medium of iron.
- w Zink is chiefly used in making brass and other metallic mixtures of the like nature (253, K, L). It is likewise used as a solder, known by the name of spelter.
- x Regulus of antimony is of a silvery white, not subject to rust, very brittle, and of a scaly or plated texture. It melts soon after ignition, and by a continuance

continuance of the heat becomes calcined, and rises in the form of white fumes. By a more moderate heat it is converted into a grey calx, fusible into a kind of glass.

The most common ore of this semi-metal is the substance called antimony. It contains sulphur in combination with the regulus, is of a dark bluish metallic colour, and its fracture resembles long shining needles. The regulus may be obtained by torrefaction, by which the sulphur is driven off, and subsequent fusion with inflammable matters. In the small way, four parts of antimony with three parts of tartar and one and a half of nitre are thrown a little at a time into a red hot crucible, and the heat raised at the end so as to fuse the mass. The detonation consumes much of the sulphur, and the coaly matter of the tartar revives a considerable part of the regulus which is found at the bottom of the crucible. Or antimony may be thrown on half its weight of small pieces of iron or nails, first made white hot in a crucible, and the heat being suddenly raised, after having covered the crucible, the mass melts, regulus of antimony being at the bottom, and the iron combined with the sulphur at the top.

The mineral acids dissolve regulus of antimony with difficulty. The marine acid has very little effect on it; but it is soluble in a considerable degree in an aqua regia, consisting of seven parts nitrous and one marine acid, or in a mixture of the vitriolic and

and marine, or even of the vitriolic and nitrous acids.

- A Much labour has been bestowed on this semi-metal by the alchemists. It furnishes some very powerful remedies, but its medical preparations require the greatest care and attention; because variations apparently of small importance in the processes are sufficient to render its effects uncertain, and even highly dangerous.
- B Regulus of antimony is used in various metallic mixtures, for printing types, speculums, &c.
- C The regulus of manganese is a semi-metal of a dusky white colour when newly broken, which grows brown by spontaneous calcination on exposure to the air. It appears to be less fusible than iron, the larger pieces being scarcely ever globular. It is very hard and brittle, and becomes spontaneously calcined in the air, so as to fall sometimes into a brownish black powder, heavier than the regulus; a circumstance which does not happen when it is inclosed in a dry, well corked bottle. Its powder is magnetic.
- D Manganese is the calx of this semi-metal. Its colour is either white, blue, green, yellow, red, brown, or black, according to its less or greater calcination, and the nature of the substances it may be contaminated with, of which calx of iron is the chief. The brown or black calx is too much calcined to be soluble in acids, and has less attraction for vital air than any other substance except nitrous acid.

If a globule of micronesian salt be melted on a piece of charcoal, by means of the blow pipe, and a small portion of the black calx of manganese be added, a glass will be formed of a bluish red, or if the proportion of manganese be greater, of a full red. The tinge will however totally disappear if the fusion be continued with the interior or well-defined apex of the flame. The brown or exterior part of the flame restores the colour. And this may be repeatedly done. The smallest particle of nitre added to the clear glass instantly restores the red colour: but vitriolic salts contribute to discharge it, as do likewise metallic calces, though these communicate each a tinge peculiar to itself.

The explanation of these facts appears to be this: the proper tinge communicated to glass by calx of manganese, when highly calcined, is red, but manganese with a less proportion of vital air is colourless. The fusion by the interior apex may be considered as a fusion in a close vessel, because the surrounding flame defends the globule from the contact of the air on the greater part of its surface. The reduction effected by the charcoal is therefore permanent, and produces the effect of rendering the globule transparent. But when the exterior flame is used, this is not the case; for the circumambient air, touching the globule in a much larger part of its surface, combines with it more speedily and in a greater quantity, than the small surface of contact between the globule and the charcoal is capable of absorbing.

The

The colour therefore returns. The nitrous acid in mine calcines the manganese. Vitriolic salts are decomposed and become sulphureous by contact of the charcoal, and thus attract vital air. Metallic calces, as well by the coaly matter they often contain, as by their own nature, are more disposed to perfect combustion than the calx of manganese, and therefore destroy the red colour. That these changes do not depend on the greater or less quantity of combustible matter that may be supposed to be imparted by the interior or exterior apices of the flame, is clear, from the changes not taking place when the globule rests on a support of pure gold or silver.

- The same phenomena with small variation take place in other glasses. Hence a principal use of manganese is made by the glass makers, in clearing their glass from the green tinge imparted to it by calx of iron, from which they cannot with sufficient facility free the materials they use. The green colour arises from iron not sufficiently calcined; manganese being therefore added in a certain dose, affords enough of vital air to render the glass colourless. But if the dose be not duly proportioned, either its own red colour or the green will prevail; the latter of which is thought to be the best.

- A remarkable effect of combustion from the vital air in the calx of manganese, is seen in the ore called black wad, from Derbyshire. It is a brown pulverulent mass, and used as a pigment. If half a pound of this be dried before a fire,

fire, and afterwards suffered to cool for about an hour, and then two ounces of linseed oil be gradually poured on it and loosely mixed, in somewhat more than half an hour the mixture will grow gradually hot, and at last burst into a flame. This effect seems to be analogous to the inflammation of oils by nitrous acid (188, D).

The vitriolic acid attacks the regulus of manganese, and extricates inflammable air. A spongy substance, of the same figure as the regulus, however remains, which is probably an impurity. Alkalis precipitate a white calx soluble in acids.

The black calx when well calcined is sparingly taken up by the vitriolic acid, and this portion seems to be that which had not been well calcined; for the remainder altogether rejects the acid. That this calx is insoluble (233, 1) from an over dose of vital air, is rendered clear, by adding sugar, honey, or any combustible substance, as by that means the solution is promoted and completed. The metals, not excepting even gold itself, produce the same effect.

The nitrous acid dissolves regulus of manganese with effervescence, occasioned by the production of nitrous air. A small residue is left. This acid acts very sparingly on the black calx.

The marine acid dissolves the regulus and also the white calx. It likewise takes up the black calx, which communicates to it a red colour, and takes off as much vital air to the acid as is necessary to

its

its solution. The aerated part flies off in yellow vapours, smelling like aqua regia (191, s).

N Regulus of wolfram* is a brittle semi-metal of a steel colour. Its specific gravity exceeds that of every other body in nature, except platina and gold (17, w); and it has not been fused into any mass of considerable magnitude, being more refractory than manganese.

O The ores of this semi-metal are the tungsten, a ponderous substance of a grey colour and lamellar texture, containing the metallic calx, or acid united
P to about its own weight of calcareous earth: and wolfram, a mineral of a still greater specific gravity, of a brownish black, always opaque, internally shining, almost like a metal, and of a crystallized form. This last is only found in tin mines, and contains about two thirds calx of wolfram, together with the black calx of manganese and calx of iron.

Q If pounded wolfram or tungsten be digested in the marine acid, the manganese and iron of the former, or the calcareous earth of the latter, will be taken up in part, or extracted from the external parts of the molecules. The residuum, after edulcoration with water, being digested with volatile alkali, the wolfram calx, or acid, will be taken up in part, or extracted from the surface. The residue, after edulcoration, will be again acted upon by the ma-

* The discoveries of Scheele, Bergman, and the De Luyars, are to be found in "A Chemical Analysis of Wolfram." Printed in London in the year 1785.

rine acid, which seizes another stratum of particles that were in the former digestion defended from its action by the wolfram calx, which the digestion in volatile alkali has removed. Volatile alkali being again applied, and the alternation continued for many vicissitudes, the mineral becomes almost entirely dissolved; the portions of acid contain either the calces of manganese and iron, or calcareous earth, according to the mineral made use of; and the volatile alkali contains the acid of wolfram. The addition of nitrous acid to this last precipitates a salt, consisting of the calx of wolfram, volatile alkali, and nitrous acid. This salt is soluble in water, though sparingly, and has acid properties. The first discoverers, Scheele and Bergman, called it acid of tungsten.

Fusion of the ore with vegetable alkali, with solution in distilled water, will afford a solution of the calx of wolfram in the alkali. This being evaporated to dryness, may be deprived of the alkali by boiling with nitrous acid, and decantation, for two or more times. The adhering acid may be driven off by calcination, and leaves the pure calx of a brimstone yellow. The same calx is also obtained by calcining the precipitate (280, R) from volatile alkali, the nitrous acid and the alkali being driven off.

The pure calx is not soluble in water, but makes, by trituration, an emulsion of sufficient subtlety to pass the filtre, and which does not entirely subside in three months. It has not this effect

- effect with the vitriolic, nitrous, and marine acids. It is completely soluble in caustic vegetable alkali, by the moist as well as the dry way. A solution in water, and also in volatile alkali, of the precipitate by nitrous acid, from the volatile alkali being added to lime-water, regenerates tungsten, the acid and alkali being found in the superfluent liquor.
- v From the strong disposition of the calx of wolfram to unite with alkalis and with calcareous earth, and its insolubility in acids, it may properly be considered as a metallic acid, though it may not possess enough of vital air to exhibit all the usual properties.
- v By treatment in a crucible with charcoal, with a strong heat, the calx of wolfram is revived into a regulus, being a brown mass, consisting of a congeries of metallic globules, with a loss of two fifths of its weight. Calcination turns it yellow as before, and its weight becomes augmented about one fourth.
- w This regulus is insoluble in the vitriolic and marine acids. The nitrous acid, and aqua regia, dephlogisticate it, and convert it into the yellow calx (280, §). It mixes with other metals, and forms peculiar alloys. Its calces tinge glass.
- x Molybdena is a mineral substance, resembling plumbago, but its laminæ are larger, brighter, and in some degree flexible, so as to be very difficultly reduced to powder. In an open fire it is almost entirely volatile. It is composed of sulphur

phur combined with a metallic acid. No acids act on it but the arsenical and nitrous. The first combines with its sulphur, and forms orpiment: the latter, five times distilled from it, communicates vital air, and forms the molybdenous and vitriolic acids. This last acid may be washed off with water, which at the same time carries off a portion of the acid of molybdena.

This acid is in a white dry form, very sparingly soluble in water. It has all the general properties of acids, and others peculiar to itself. It is precipitable from its solution in water by Prussian alkali, and by galls. Distilled with three times its weight of sulphur, it again produces molybdena.

It has been reduced into a metallic form.

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C H A P. XX.

CONCERNING PYROPHORI; THE PHOSPHORUS OF BOLOGNA, OF BALDWIN, AND OF CANTON; OILS, ARDENT SPIRIT, AND ETHER.

THERE are many compositions that take fire on exposure to respirable air. They are called pyrophori. One of the best is thus made. Two parts of burned alum, or alum kept in a red heat till it has ceased to expand and swell; one part of charcoal, and one part of vegetable fixed alkali being mixed in powder, are to be lightly pressed

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into

into the bowl of a tobacco-pipe, or a small crucible, so as to fill it about half or three fourths; the remaining space is to be filled with fine writing sand, for the purpose of preventing the immediate access of air. This vessel being placed in a good fire, the sand is agitated for a few minutes by the escape of elastic fluid, and soon afterwards a blue flame is seen to issue from the mass, which continues about a quarter of an hour. The red heat being continued for twenty minutes or longer, after this appearance has ceased, the vessel may be taken out of the fire, and when it is perfectly cool, the pyrophorus may be knocked out, and must be immediately put into a well closed phial. A piece of this exposed to the air for a short time, becomes ignited, with some slight appearances of deflagration. and an

• hepatic smell. The particular or immediate cause of the accension of pyrophori has not been well explained. It seems as if the combustible substance made use of, enters into the composition of an hepar, in which the connection of the inflammable matter is so slight, that it can unite with pure air with sufficient rapidity to produce ignition and combustion (125, N).

- It is a very general property of bodies, after exposure for a short time to light, to emit it again for some time after it ceases to fall upon them, as is easily proved by receiving them in a darkened room. Metals and water have not this property *, neither do orgs, vitriols, or oil, possess it in any

* Priestly's Optics, p. 369.

considerable degree. Other bodies possess it in various degrees. Heat causes the light to be emitted more quickly, and consequently with greater intensity while it lasts, but the luminous appearance does not take place at all by mere heat without previous exposure to light. It is said, that coloured light is emitted again of the same colour. Among substances that possess this property in a remarkable degree, the chief are vitriolated ponderous earth, or ponderous spar, previously ignited among charcoal; called the Bolognian phosphorus: nitrated calcareous earth, after ignition; called Baldwin's phosphorus; and calcareous earth ignited with sulphur. This last is called Canton's phosphorus, and is thus made. Calcine oyster-shells, by keeping them in a good fire for half an hour or more, and let the whitest part be pulverized and sifted. With three parts of this powder mix one part of flowers of sulphur. Let the mixture be rammed into a crucible of about one inch and a half in depth, till it be almost full, and let it be placed in the middle of the fire, where it must be kept red hot for one hour at least, and then set by to cool. When it is cold, turn it out, and cutting it into pieces, scrape off or select upon trial the brightest parts, which, if good, will be a white powder, and may be preserved in a dry phial with a ground stopper. Exposure for a few seconds to the light of the day, will cause it to shine in the dark; or it may be rendered luminous by an electric explosion made near it.

- H** Oils are liquids, in general less fluid than water, and remarkably less sonorous when poured out. When heated so as to fume, they are easily set on fire, and burn with a luminous flame. If the combustion be not managed so that respirable air may have sufficient access to all parts of the flame, much smoke is produced. They leave a coal behind.
- I** In the combustion of oil, for the æconomical purpose of giving light, a wick is made use of, consisting of vegetable fibres, usually cotton. These being dipped in the oil, one end of the wick is made to protrude, and is set on fire. The capillary attraction (1, 46, w) supplies more oil, accordingly as that in the heated part of the wick is carried off by the rarefaction and combustion. If the wick be too large, the internal part of the flame will want air; if it be too long, more oil will issue out of its pores in vapor than can be completely burned. In either case smoke will be produced. But by a due attention to the figure and magnitude of the wick and the supply of air, a bright flame may be produced without smoke. This is done in the excellent lamp of **ARGAND**.
- K** Oils are distinguished into the unguinous and essential. The former are insipid, and without smell, not soluble in ardent spirit, nor volatile in the heat of boiling water. Acid of sugar has been obtained from them. The latter have a strong smell and taste; are soluble in ardent spirit, and volatile in the heat of boiling water. Animal fats

fats resemble unguinous oils, excepting the oil obtained by distillation from the gelatinous substance of animals. This may be brought to resemble ether by repeated distillations. Resins are of the nature of essential oils.

Spirit of wine, or ardent spirit, is obtained by L distillation from substances that have undergone the vinous fermentation (212, F, H), and are not arrived at the acetous. When well concentrated, it is very volatile and fluid, has never yet been congealed, mixes with water in all proportions, and with an affinity sufficiently powerful to take it from most saline substances; highly inflammable, so as to burn without a wick, even when cold, and produces neither foot nor coal. Its flame is bluish, and not very luminous.

Ardent spirit unites with acids, and renders N them milder than can be supposed to arise from mere dilution.

If vitriolic acid be added to spirit of wine, and O the mixture submitted to distillation, the products are first a very pure spirit of wine, next a liquor called vitriolic ether, and, lastly, an oil. In this process it appears, that the action or combination of the acid is capable of converting the spirit into oil, and that ether is an intermediate substance between spirit and oil.

Ether is soluble in ten times its weight of water. P It is extremely light (18, w), and so volatile, as to convert water into ice in a warm room, if the water be included in a small bottle, or tube,

constantly wetted on the outside with this fluid (123, κ). It is highly inflammable, burning with a white luminous flame, and some appearance of soot, but leaves no coal.

- Q Ethers may be made with other acids as well as the vitriolic.

B O O K III.

S E C T I O N II.

Of Magnetism.

C H A P. I.

CONCERNING MAGNETISM; THE METHODS OF
COMMUNICATING IT, AND THE VARIATION
OF THE COMPASS.

THAT remarkable property which iron possesses, ^A of becoming magnetical, seems to stand alone among natural phenomena. It is the only instance of permanent attraction which is sufficiently strong to become the object of vulgar attention; and philosophers observe its effects with surprize and admiration; while the most cautious and rational are obliged to confess that the cause is entirely unknown.

A strait bar of iron, which in the northern ^B parts of the world has stood a long time in a vertical position, is found to have acquired the property of attracting other iron at its extremities; and, if supported in a vessel, so as to float at liberty upon water, conforms itself to a direction nearly in the plane of the meridian; the end,

which during its perpendicular situation was downwards, always pointing towards the North. This bar is said to be magnetical; and the unknown cause of these and other concomitant effects is called magnetism.

- c Magnetism may be given to iron, or rather steel, by many methods. The disposition to conform to the plane of the meridian is called polarity, and is of such importance in its application, that the modern art of navigation could not be practised without it. The mariner's compass is thus constructed. A flat thin bar of steel, rendered magnetical, is fastened underneath a circular card, divided into points (56, *κ*), so that the direction of its length may correspond with the line *ns* fig. 132). This bar is perforated in the middle; and in the perforation is fixed a brass cap, hollowed out conically, which consequently is in the center of the card. The card thus provided with a magnetical bar, is then supported horizontally, by placing the cavity of the cap on an upright metallic point, and is therefore at liberty to revolve into any horizontal position. But the bar, which is usually termed the needle, conforming itself to the meridian, causes the fleur de lis of the card to point to the North: consequently, the other divisions must denote the respective bearings of the points of the compass. This card being thus suspended in a hollow box, and defended from the wind by a pane of glass, with the addition of a contrivance to prevent the effects of the agitation

tion of the ship, is the mariner's compass; by the help of which, vessels are enabled to steer their course with safety in the darkest night, and at any distance from shore.

In the examination of the magnetism of various bodies, as, for example, platina (240, B) or Nickel, it may be of importance to know the degrees of magnetism as discoverable by experiment, which are the following. The weakest is when a body floating on water slowly follows a strong magnet, held almost touching it; the next is when the magnet can repel as well as attract the body; a still stronger degree is, when the body conforms its position to that of the magnet held over it; the fifth is, when the body left to itself assumes a particular position, and returns to it when disturbed; the sixth is, when the body, taken out of the water, and brought near a light compass needle, causes it to deviate from the magnetic meridian. All stronger degrees of magnetism may be observed by less delicate methods.

The ends of a simple magnetical bar are called its poles; and that pole, which, when at liberty, would point to the North is called the North-pole, and the other is called the South-pole.

Universally, in two magnetical bodies or magnets, an attractive force obtains between the North-pole of one, and the South-pole of the other, and a repulsive force obtains between poles of the same name. But the repulsive force which exists between

tween poles of like names, but unequal power, is changed into attraction, when the distance is sufficiently small. From these criterions it is easy to determine the names of the poles of a magnetical bar, by applying it near the suspended magnet, whose poles are known.

e If a bar of iron, which is not magnetical, be held in a vertical position, in North latitude; its lower point becomes a North, and its upper a South pole; and these poles may be reversed instantly, and as often as required, by reversing the position of the ends; for the lower will always be North, and the upper South. But a few strokes with a hammer at the upper end, will fix the poles in their last position, so that, after the reversing it, the hammered end will still continue to be south, though lowest. Yet, the magnetical power is much the greatest when the hammered end is uppermost, and the effect of the hammering disappears in a few hours.

H A bar of iron being suspended on an axis, in a very nice equilibrium, the North end preponderates when the bar is rendered magnetical, so that it becomes inclined to the horizon, in an angle of about seventy degrees in these latitudes. This is called the dip, and decreases in places more to the southward, and even becomes inverted in places situated considerably on the other side of the equator. The bar thus suspended is termed the dipping-needle.

Magnetism may be given to a bar of iron, by placing it firm in the position of the dipping-needle, and rubbing it hard all one way with a polished steel instrument. Iron also becomes magnetical by ignition, and quenching it in water, in the position of the dipping-needle.

The touch of a magnet communicates the like virtue to other iron, but the quantity or degree which the same magnet can communicate, depends greatly upon the manner in which the touch is performed. If two equal, straight and uniform magnetical bars, with flat ends, be placed together endwise, the contrary poles touching each other, they will form one single magnet, and will communicate a strong degree of magnetism to another bar by the following process: let the last mentioned bar be laid in the direction of the magnetical meridian, and let the others, each of which ought to be at least as long as the bar to be impregnated, be laid upon it in their conjoined state, so that the place of junction may be over the middle of its length, and their poles in the proper direction. Then separate the two magnets, by drawing them asunder along the surface of the bar, and continue to separate them till their ends are at a considerable distance from its ends. Join them again, without altering the situation of their poles, by a circular motion of the hand, so that they may meet at some distance above the center of the bar, and lay them again upon it as before.

Repeat

Repeat this operation on both sides of the bar-till it has acquired a sufficient degree of magnetism. The maximum is generally obtained after twelve or fourteen strokes.

- L** A bar of iron receives the touch more strongly when it is supported by, or in contact with, another much larger; and a combination of magnetical bars will produce a much greater effect than a single one. Soft steel acquires the magnetical power more readily, but does not preserve it so long as hard steel. On these, and other considerations, experiments have been multiplied, and various methods invented, of giving to steel the utmost degree of magnetism it is capable of receiving. For example, six bars of steel may be rendered slightly magnetical, by affixing each successively to a poker, and stroking it several times from bottom to top with the lower end of an old pair of tongs; care being taken to keep both the poker and tongs in a vertical position. For, these utensils, by long standing in a vertical position, are almost always possessed of a fixed magnetism; the lower ends being North poles. Now, if four of the six bars be united into a thick compound bar, the magnetism of the remaining two may be greatly increased by touching with it. These two bars may then be substituted in the room of the two outermost in the compound bar, which will become more powerful by the exchange, and the two, which were taken from the compound bar, may be touched in their turn. Thus, by reiterated changes,

changes, and touching, the bars will at length acquire as much magnetism as they are susceptible of; and more than they can retain for any long time.

The force of magnetism is exerted through all substances, iron excepted, and it has not been observed that it suffers the least diminution by the interposition of any foreign matter. Magnetism is destroyed by ignition; and a heated bar of iron is not attracted by the magnet till it is just upon the point of losing its redness.

The loadstone is a ponderous ore of iron, usually of a dirty black colour, and hard enough to emit sparks with steel. It is found in most parts of the world, and possesses a natural magnetism, acquired most probably from its situation or position with respect to the earth. This magnetism may be, as it were, concentrated, and made to act much more strongly by covering its polar extremities with steel. The steel thus applied is termed the armour of the loadstone, and requires some management, as to figure and thickness, to produce the greatest possible effect. Formerly all magnetism was originally obtained by communication from the loadstone, but the power of impregnated steel-bars so much exceeds that of the natural stone, that this latter is little esteemed, except as an object of curiosity. The magnetism of the loadstone is in all respects similar to that of a bar of iron or steel.

The attraction or repulsion of two magnets decreases as the distance increases, but not according
to

to any ratio of the distance. On this account a magnetical bar, which is at liberty to assume any horizontal position, as, for example, a needle floated on water by means of cork, or the needle of a mariner's compass, being brought into the vicinity of another magnet, will assume such a situation as shall conform to the attractive and repulsive powers as much as possible. Thus, if a suspended magnetical needle be brought near another magnet, it will place itself in a position parallel to the axis of the magnet, if the poles of contrary names in each be mutually equidistant; but if the North pole of the suspended needle be nearer the South pole of the magnet than the two other poles are to each other, its North end will be most attracted, and consequently must incline, so that the axis of the two magnets will form an angle greater or less, according to circumstances.

- Q Suppose now a small magnetical bar, suspended so as to be capable of assuming any position whatsoever, be placed upon, or near the surface of a very large globular magnet. It is evident, in this case, that the two ends of the small bar, being respectively attracted by the contrary poles of the globe, will always be found in a plane passing through those poles: or in other words, if circles or meridians be supposed to be described on the globe, intersecting each other in those poles, the magnetical bar must always be in the plane of one of them. But its situation, with regard to the spherical surface, will be governed by the excess of attraction

attraction in the nearest pole. If the bar be suspended immediately over the North pole of the magnet, it must stand perpendicularly, with its South end downwards; but if it be gradually removed along the surface, towards the South pole, the increasing action of this last pole will cause it gradually to incline that way. At the equator it will rest parallel to the surface; and in approaching still nearer the last mentioned pole, its North end will incline towards the surface, till at length it will stand perpendicularly over the South pole of the great magnet, with its North end downwards. For the sake of conciseness, the poles of the great magnet are supposed to be equally strong; which, however, is seldom the case.

This reasoning may be exemplified by placing a small piece of sewing-needle on the surface of a spherical magnet or loadstone. Its position is found to vary according to its situation with respect to the poles. For the same reasons, steel-filings, gently dusted through a rag upon a magnet, adhere to it in a very curious and amusing manner. The filings, acquiring magnetism by the contact, adhere together, and form a number of small magnets, which arrange themselves in conformity to the attractions of the poles of the original magnet.

From observations of this nature, it was very early supposed, that the globe of the Earth acts as a large magnet, upon all other magnets: whence they naturally tend to conform to the meridian or
line

- T** line which joins the poles of the Earth. And the dipping of the needle is readily shewn to arise from the vicinity, and consequent stronger attraction of the pole towards which the inclination is made.
- v** The needle of the mariner's compass varies from the true direction of North and South. The angle formed between the magnetical axis of the needle and the meridian of a given place is called the variation of the compass, and differs in different places both in quantity and direction of the needle. From the phenomena of the variation it is proved, that the magnetic poles of the Earth must be more in number than two, and that they do not coincide with the poles about which the diurnal rotation is performed.
- v** The variation of the compass does not continue fixed and unalterable at a given place. Thus, at the Cape of Good Hope in Africa, near which, at its first discovery by the Portuguese, there was no variation; the North point of the compass, in 1622, varied about 2° to the westward: in 1675, it varied 8° W. in 1700, about 11° W. in 1756, about 18° W. and in 1774, about $21\frac{1}{2}^{\circ}$ W. Regular, though very different mutations have been observed in almost every other place on the globe. The needle of the compass is likewise subject to a small diurnal change of position, and is sometimes considerably agitated during the appearance of the aurora borealis.
- w** The observations which relate to the magnetism of the Earth have not been continued long enough

to afford a foundation for a good theory. Dr. Halley's hypothesis, though formed near a century ago, still possesses as great a share of probability as most that have been offered since. He supposes the Earth to consist of two distinct parts, an external shell, or hollow sphere, and an internal nucleus or globe, loose and detached in the cavity, having the same center of gravity with the external part. Each of these parts he regards as a separate magnet, endued with two poles, their magnetical axes not being coincident. A compass-needle on the external surface must therefore be acted upon, as if by a magnet with four poles. From the phenomena he determines the situation of the several poles, and thus explains the variation. But as the variation changes in process of time at any given place, it follows, that these poles do not keep the same position with respect to the surface of the Earth, and to each other. This movement he accounts for, by supposing that the diurnal motion of the Earth was impressed from without, and that the velocity of the internal part, or nucleus, is somewhat less than that of the external part, or shell. Consequently the nucleus must seem to revolve slowly to the westward, and its poles must describe lesser circles about the poles of the Earth. And as the relative position of the four magnetical poles to each other, and to the poles of the Earth, is changed, so must likewise the direction of the

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needle, or the angle it makes with the meridian, be altered.

y Thus, a kind of regularity prevails in the increase and decrease of the variation, and also the direction of the variation which ships observe as they sail to various parts of the ocean. In the Atlantic ocean to the North, and eastward, and all over the Indian ocean, except in the bay of Bengal, a westerly variation obtains; but to the westward of a certain line, at which there is no variation, all along the coast of South America, and in the Pacific ocean, as far as the 140th degree of west longitude, an easterly variation is observed; and in the whole Pacific ocean besides, the variation is probably to the west, unless it may be conjectured that an easterly variation may be found in the regions to the northward.

z When the variation changes quickly in running upon a parallel, as is the case in the southern Atlantic, and great part of the Indian ocean, the longitude may be determined with a considerable degree of correctness at sea. For the magnetic azimuth of the Sun may be easily observed in moderate weather to the certainty of a less error than ten minutes of a degree; which in the southern Atlantic ocean answers to about twice that quantity in longitude. By comparing the observed variation with a chart, the longitude may be known. The principal impediment in the way of this method is, the want of such a chart occasionally renewed.

The best modern opinion concerning the cause A of the change of variation of the compass is this. From the magnetism of the Earth as well as from the products ejected by volcanos (227, F), it is established that vast quantities of iron exist in the bowels of the Earth in various states. The same volcanic eruptions, and the phenomena accompanying them, likewise shew that chemical processes, on a scale of prodigious magnitude, are continually carried on in those regions. The ferruginous combinations being varied by these, it must happen that immense masses will be either more or less phlogisticated, according to the nature of the process by which such change is made. Now it is well known that iron and its combinations are more susceptible of magnetism the nearer the metal approaches to the reguline state; and consequently the properties of the whole terrestrial magnet must change accordingly.

B O O K III.

S E C T. IV.

Concerning Electricity.

C H A P. I.

OF THE ELECTRIC MATTER; AND THE METHODS
AND APPARATUS FOR MAKING EXPERIMENTS
WITH IT.

- A If a tube of glass, an inch and half in diameter and about three feet long, be rubbed, by repeatedly drawing the hand or a piece of leather from one end to the other, it will become electric. So that small, flashes of divergent flame, ramified somewhat like trees bare of leaves, will dart into the air, from many parts of the surface of the tube, to the distance of six or eight inches, attended with a crackling noise; and sometimes sparks of more than a foot in length will fly along the tube to the rubber. This luminous matter is called electricity, or the electric matter, and will fly from the tube to other bodies brought within a certain distance.

If

If a homogeneous body be presented to the excited tube, so as to receive electricity from it, and the electricity remain at or near the end or part presented, without being communicated to the rest of the body, it is called a non-conductor or electric. But if, on the contrary, the electricity be thus communicated to every part, the body is called a conductor, or non-electric. In the usual temperature of the atmosphere, metallic substances, charcoal, and water, are conductors; most other bodies are non-conductors.

A conductor cannot be electrified while it communicates with the earth, either by direct contact or by the interposition of other conductors, because the electricity is immediately conveyed away to the earth. But if a conductor be supported by an electric, so as not to communicate with the earth, it is said to be insulated.

The greatest quantity of electricity is collected on the surface of a non-conductor, when it is rubbed by a conducting substance. If the rubber be insulated, it will also be put into an electric state, so that sparks will pass between it, and other neighbouring bodies.

If an insulated conductor be electrified, either by friction, communication, (302, a) or otherwise, it will be deprived of its electric state by the drawing of a single spark from any part thereof by another uninsulated conductor, because of the facility with which the electric matter is conveyed through its substance. But non-conductors, similarly treated,

are deprived of their electric state only in the vicinity of the place from which the spark was drawn.

- I A mutual attraction is exerted between a body in a state of electricity, and other non-electrified bodies, which last, if not large and heavy, will fly through the air to the electrified body, where they remain till they have, by communication, acquired the same state, when they are repelled. If an un-insulated conductor be at hand, it will attract the small body thus electrified, and deprive it of its electric state. So that it will be again attracted by the electrified body, and repelled as before, and will continue to pass and repass between the two for many vicissitudes, till the electric state is entirely destroyed.
- K No experiments have yet been made, that shew wherein the difference between electrics and non-electrics consists; but whatever the conducting power may depend on, it seems to be governed by the heat of the body: glass, resin, baked wood, air, and many other non conductors, are conductors when made very hot; and, on the contrary, ice cooled to 13° below 0, on Fahrenheit's scale, becomes a non-conductor or electric body.
- L There is therefore some ground to conjecture that the disposition to conduct electricity is produced in metals by a very low degree of heat, in water by a greater, and in resins and glass by degrees still greater; or generally that there is a certain degree of heat at which a given body may be
at

at the medium between perfect conducting, and non-conducting, above which degree it becomes a conductor, and beneath, a non-conductor. If this *m* be true, it will follow, that conductors are bodies whose electric or non-conducting state is placed at a temperature far below that which is usual in the atmosphere, and that non-conductors are those whose conducting state is placed at a degree of heat far above the mean temperature.

That electricity is real matter, and not a mere *n* property, seems to be evident from a variety of circumstances. When it passes between bodies, it divides the air, and puts it into those undulations (65, *n*) in which sound consists. It emits the rays of light in every direction, and those rays are variously refrangible, and colorific, as other light is. And if light be acknowledged to be matter, it is contrary to reason and experience to suppose, that the thing which emits it should not likewise be material. Neither are the other senses unaffected at its presence; its smell is strongly phosphoreal or sulphureous, so that when the air of a room is rendered highly electric, many persons have complained of an unusual and disagreeable sensation in the head from that cause. The sense of feeling is a witness of its presence, not only from the sparks, which, when received from the conductor of a powerful machine, are very pungent, and will pass through two or three persons standing on the ground, but also from the shock, whose effects are to be described: and a stream of the electric

matter received on the tongue has an evidently subacid taste, which remains some little time after.

- o As the exciting a tube is very laborious for the operator, and the electricity procured by that means is small in quantity, globes or cylinders are much more used. These, by a proper apparatus, are made to revolve on their axes after the manner of a grindstone, and a rubber of leather is applied to the equatorial parts of the revolving glass, which become electrical by the friction. The electricity of the globe is received by a metallic conductor, insulated by a glass-foot, or supporter. This conductor being constantly electrified, and at the same time steady and motionless, is much better adapted for making experiments than the globe itself,

- p A cylinder or globe thus fitted up to revolve on its axis, and provided with a rubber and an insulated conductor, is called an electrical machine. The contrivances for the revolution of the cylinder or globe vary in different machines, as likewise the method of insulating the conductor. The conductor is in general supported by a stick of varnished glass or baked wood, and sometimes it is suspended by silk strings.

- q Fig. 162, represents an electrical machine. The glass cylinder c, is one foot in diameter and nineteen inches long, and is turned by a wheel and string, as shewn in the drawing. The rubber or cushion is supported behind the cylinder by two upright springs that appear beneath, and are fastened

fastened to two cross bars of glass. *s* is the conductor supported on two pillars of glass. From the end nearest the cylinder, issue several points; and at the other end the ball *r* projects by means of a wire. The ball *s* is not insulated, and serves to draw the spark from *r*. *D* is a chain, usually hung to the cushion. The sparks given by the conductor of a machine of this construction and magnitude are from 12 to 14 inches long.

Fig. 163, is a drawing of Nairne's patent electrical machine. The cylinder *c* is seven inches in diameter and about one foot in length, but the length of the rubber is no more than eight inches. The working parts at the end of the cylinder are entirely of wood, and are supported by two pillars of varnished glass each of a foot in length. The conductors *A* and *B*, are supported by like pillars of the same dimensions. The two conductors are made of tin, and lie parallel to the length of the cylinder. They are exactly alike, excepting that the rubber is fixed between the conductor *A* and the cylinder, and a row of metallic points issue towards the cylinder from the other conductor *B*. The insulation of this excellent small machine, is so perfect, that on the addition of a larger conductor to either of the others, it will give dense sparks of nine inches long to a ball of $2\frac{1}{2}$ inches diameter.

C H A P. II.

CONCERNING EXCITATION ; THE TWO DIFFERENT STATES OF ELECTRICITY, AND THE EFFECTS OF POINTED CONDUCTORS.

- S** VERY little electricity is excited by the friction between two electrics or two conductors. The most favourable circumstances for producing this effect, seem to be, when a perfect electric is rubbed by a perfect conductor (302, o).
- T** The rubber of an electrical machine is usually made of soft leather stuffed with hair, and the rubbing part is smeared with an amalgam of zink and quicksilver with a little tallow, the whole being so proportioned as to have the consistence of paste. The glass cylinder in its rotation, passing in contact with this metallic soft substance, becomes electrified, and its electricity is prevented from flying back in sparks to the rubber or being dissipated into the air, by a piece of silk sewed to the rubber, and passing over its surface and thence half way round the cylinder, to which it adheres by the electric attraction.
- U** The electricity thus excited, is much stronger in dry frosty weather than when the atmosphere is damp, and consequently a better conductor of electricity. The management of the operator will also
- 4
make

make a prodigious difference. No theory of what happens in the excitation of electrics, has been offered that deserves to be mentioned; and it is owing to our imperfect knowledge of this subject, that the most skilful operators succeed by an attention to circumstances relating to the consistence of the amalgam, the roughness or smoothness of its surface, its freshness, the position and management of the silk, and other matters that can hardly be described, so as to assist the young electrician. The following directions however succeed very well.

Every part of the apparatus must be carefully v wiped with a dry warm cloth, or old silk handkerchief, in order that the electricity, when collected, may not be conducted off by adhering moisture or damp (302, D). The amalgam ought to abound with quicksilver, and to have no more tallow than is sufficient, when applied to the cylinder, just to diminish its brightness without smearing. It must be rubbed on the rough side of a piece of leather, pasted on a card, in very small quantity. The cushion and silk must be carefully brushed or wiped before it is put in its place. This done, turn back the silk so that its loose part may not touch the cylinder, and begin to turn the machine, at the same time applying the amalgamed leather to the cylinder. After a few turns the electricity will be heard in a kind of rustling noise near the hand and cushion. Remove then the amalgamed leather, and replace the , silk on the cylinder, to which it will immediately adhere.

adhere. The friction will now be much greater than before, as will be perceived by the difficulty of turning the handle, and the electricity will be seen along the edge of the silk in long diverging ramifications that dart into the air with noise. These fly to the points of the prime conductor when applied, and, by means of this last, the sparks may be drawn, or other experiments performed.

w It is not well settled whether a velocity of rotation in the cylinder, greater than the hand can produce with a single winch, be of any advantage in electricity. From a few trials, not sufficiently diversified, the fact seems to be, that there is a certain velocity of turning by which more electricity is obtained, in a given number of turns, than by any velocity considerably greater or less; and that this necessary velocity is least when the excitation is most powerful. A cylinder of seven inches diameter, well excited, will afford its maximum of electricity in a turn by a moderate rotation with a single winch, and the adhesion of the silk will render the turning sufficiently laborious. But whether the labour of the operator would be better employed in producing more turns in a given time by means of a wheel, though the excitation were less powerful, remains to be decided.

x If the amalgam be applied on the cushion itself, instead of a separate leather, the excitation will be more uniformly the same, though rather less strong. When the separate leather is used, it is necessary

to

to apply it to the cylinder from time to time, to keep up the excitation. One of the chief advantages of this last method appears to be, that a strong excitation may at any time be produced by taking off the cushion and wiping it and the silk very clean, at the same time that the old amalgam is scraped off the leather, and replaced by the size of a pea of fresh amalgam; whereas in the other method, it not unfrequently happens, that the operator is obliged to have recourse to a variety of manœuvres without success.

If of two conductors, separately insulated, one ^v be connected with the insulated rubber, and the other placed near the cylinder, so as to be electrified by it, they will both exhibit signs of electricity; but that conductor, which is electrified by the cylinder, will attract those bodies which are repelled by the other conductor that received its electricity from the rubber. And these conductors, if brought near each other, will emit sparks, and act on each other in every respect, stronger than on other bodies. If they be brought into contact, the electricity of the one will destroy that of the other; and notwithstanding the electric matter appears to flow or pass from the cylinder to its conductor, the two thus conjoined will exhibit few or no signs of electricity.

The senses cannot distinguish the direction in ^z which the electric matter moves. The hypothesis most generally admitted, is that electricity is an uniform fluid, capable of being rarefied or condensed,

densed, and that in the common electrical machine it passes from the cylinder to the conductor with points. On this supposition this conductor must, when electrified, possess a greater quantity than is natural to it; and since the cylinder affords very little electricity when the rubber is insulated, it will follow that it receives its electricity from the rubber; for unless the rubber be at liberty to receive an equal quantity from the earth, that is, unless it be uninsulated, it can part with but a very small quantity to the cylinder. Still retaining the same supposition respecting the course of the electric matter, it follows that the rubber, when insulated, must lose a part of its natural quantity by friction with the cylinder, and consequently a conductor communicating with it must be negatively electrified. It is not therefore so much to be wondered at, that the actions of the two conductors should be contrary, and that when in contact they should exhibit no signs of electricity; for the cylinder at the same instant that it imparts the electric matter to one conductor, exhausts an equal quantity from the other, which is connected with the rubber. If the direction of the electric matter be supposed to be contrary to what is here assumed, the effects must still be the same.

- A The principal circumstance whereon the prevailing opinion concerning this direction is founded is, that if the conductor, which derives its electricity from the cylinder, be made sharp or angular

angular at any part, not very near the cylinder, a diverging cone of electric light will be seen, whose vertex is the point itself, and the electric phenomena will be much diminished. But the conductor, which is connected with the rubber, though its effects be equally diminished by a similar circumstance, will never exhibit the cone of rays, but is only tipped at the point with a small globular body of light. The cone has been thought to resemble the rushing out or emitting of light, and the globe the appearance of the imbibing or entrance of the electric matter; whence the name of positive electricity has been adopted for that of the cylinder, and negative for that of the rubber. The terms will be used in the same sense, in this work, though it must be confessed, that the propriety of their application is still doubtful.

If electricity be produced by the excitation of a globe or cylinder of sulphur or resin, the states will be reversed; the rubber will be positive, and the cylinder, with its conductor, will be negative. This was formerly thought to depend on the nature of the electric body, and the two states of electricity were distinguished by the names of vitreous and resinous electricity, but it has since been found, that the difference, in most cases, arises from the relative smoothness of the surfaces of the electric body and its rubber when compared with each other.

It seems to be a rule, that the smoothness of the two bodies obtains the positive state. Baked wooden

wooden cylinders, with a smooth rubber of oiled silk, become negative, but with a rubber of flannel positive. Glass, made rough by grinding with emery, excited with new soft flannel, is negative, but with dry oiled silk, rubbed with whiting, positive; but if the glass be smeared with tallow, and wiped with a cloth, then the oiled silk, by rubbing, becomes polished, and the tube becomes negative, as at first; if the oiled silk be again rubbed with whiting, it excites a positive state on the greased tube; but then the silk has again acquired a polish, the tube becomes again negative. Even polished glass may be rendered negative by rubbing with the hairy side of a cat's skin.

D Bodies possessed of similar and equal states of electricity, repel each other; bodies possessed of opposite states of electricity, attract each other; and bodies in a mean or natural state are attracted by all electrified bodies whatever. But as we have no clear conception, or adequate idea, of any mechanical process by which attraction may be caused, all our reasoning on the subject must be purely hypothetical (1. 25, x), for want of probable grounds to proceed on. If ever this property of matter, whose origin at present is so little understood, should be deduced from some simpler cause, there is great reason to think that it will be in consequence of electrical discoveries.

2 If the insulated prime conductor of a machine be well polished, and without corners or angles,

it will retain its electric state very well, and will emit strong sparks upon the approach of any un-insulated conductor. If the un-insulated conductor be broad, round, and polished at the end, the sparks will be short and dense, and will produce a considerable sound; if less broad, the spark will be long, crooked, and less sounding; if the breadth be still more diminished, the conductor begins to come under the denomination of a pointed body (311, A), the electric matter passes to it from the prime conductor, through a great space of air with a hissing or rustling noise, and in a continual stream: a still greater sharpness enables the electricity to pass over a greater space, but silently, and nothing is seen but a small light upon the point. If a similar point issue from the prime conductor, and the un-insulated conductor be round and polished, the same effects happen in like situations; but if both be pointed, the electricity is more readily discharged: and in all these cases the appearance of the electric matter at the point of the prime conductor will be that which is peculiar to its electricity, a large divergent cone if positive, or a small globular light or cone if negative, and the light at the point presented to the prime conductor will be distinctive of the contrary electricity. Whether a pointed conductor be electrified positively or negatively, if the nose be brought near the point during the electrization, a wind will be felt blowing from the point, and the

sense will be affected with a sulphureous or phosphoreal smell.

F The reaction of the force by which the air is put into motion, is exerted on the pointed body. This is shewn by a pleasing experiment with an electrified wire; thus to the middle of the wire, or rather between two wires that lie in the same line, is affixed a center-cap like those used in sea-compasses, so that the wire may easily be moved on a point in an horizontal direction, as magnetical needles are; and the ends of the wire are pointed and bent contrary ways, to point in the direction of the tangent to the circle described by them. Now if this wire thus suspended on a point, be insulated and electrified, its sharp ends will become luminous, and it will revolve in a direction contrary to that in which its ends are bent; or if it be suspended on an uninsulated point, and brought near the electrified prime conductor, the same effect will follow.

G It may be thought strange that the air should issue from an electrified point, whether its electricity be positive or negative. It is easy to conceive that the issuing out of the electric matter may cause the air to move in the same direction, but it appears strange, that the electric matter rushing towards a point should cause the air to move directly contrary, that is to say, likewise from the point. But if the circumstance be examined more narrowly, the difficulty will vanish. For it is highly probable that the electric matter
passes

passes too swiftly (I. 40, z) to excite any motion in the air but that undulation wherein sound consists (65, n); to which may be added, that if the electric matter do act on the air to put it in motion, the air must react with an equal force; and therefore that a current of air blown against the course of the electric matter must affect its appearance, by retarding the rays and deflecting those against which it struck obliquely: the contrary to which is by experience, known to obtain; for the luminous cones (314, e) are not sensibly affected by such treatment. The air being thus indifferent as to the motion of the electric matter, its motion may be shewn to depend on the established principles of electricity. The point is electrified either positively or negatively, and the air, immediately opposite and contiguous to the point, must, by the emission or exhaustion of the electric matter, become strongly possessed of an electric state of the same kind with that of the point: it is therefore repelled (313, d) and replaced by other air which is also electrified and repelled, by which means a constant stream is produced blowing from the point, and that equally whether the electrization be positive or negative. And, as action and reaction are equal and contrary, the point repelling the air must itself also be equally repelled in the contrary direction; whence the horizontal wire above described is turned, and that always one way, namely, contrary to that in which the air is moved, or to the direction of its bent points.

C H A P. III.

OF THE COURSE OF THE ELECTRIC MATTER
THROUGH THE COMMON AIR, AND THROUGH
AIR VERY MUCH RAREFIED, WITH A DESCRIPTION
OF AN INSTRUMENT FOR DISTINGUISH-
ING THE TWO STATES OF ELECTRICITY.

- H THE air, being a non-conductor, must be classed among electric bodies; and the prime conductor of an electrical machine being surrounded with it retains its electric state much better than it would do without that circumstance. For the electric matter cannot pass to or from the conductor with the same facility as if this impermeable substance were not interposed.
- I When air is spoken of as impermeable and electric, it must not be understood as being perfectly so, but as being mostly composed of non-conducting parts. There is always moisture enough in the air to restore the natural state to electrified bodies in a few hours. It is likewise permeable, as all other electrics are, by the force of the electric matter which divides it or separates its parts: when this happens to a solid electric, a hole is made through it.
- K Long sparks are always crooked in various directions, like lightning; which seems to be caused

caused by the electric matter passing through those parts of the air in which the best conductors are found. . Indeed there is reason to think that electricity always requires a conductor to enable it to pass from one body to another. For if a glass syphon, whose legs are equal, and respectively more than thirty inches long, be filled with boiling mercury, and the ends inverted into basons likewise containing mercury, a double barometer (31, z) will be formed, whose upper or arched part will be absolutely void of air. Then if one of the basons be insulated and electrified, the electricity will not pass from the mercury in one leg, through the void, to that in the other; but upon admitting a small bubble of air, it is immediately seen passing through the vacant space in the form of bright flashes or flames. In the vacuum of the air-pump the electric matter will pass and appear luminous between conductors, how distant soever, forming a beautiful appearance, that very much resembles the northern lights or aurora-borealis. But it is found that in high degrees of exhaustion the light is less the less air is left in the receiver. It seems, on consideration of these circumstances, that the electric matter cannot pass through the more perfect vacuum, for want of a conductor, but that the conducting part of the air when introduced, answers the purpose, while the resistance of the electric part, being very small, on account of the rarefaction, suffers it to pass from one con-

ductor to another, through much greater spaces than it can pass through in the open air.

- L This opinion is somewhat more confirmed by the observation that the electric matter forces conducting bodies into its path. If a drop of water be laid on the prime conductor, in a positive state, very long sparks may be drawn from it, the drop will assume a pointed or conical shape, and wet bodies which are held near it: a proof that the water is thrown off. If the same experiment be made with melted sealing-wax, the appearance is very peculiar and amusing. The sealing-wax must be dropped on or stuck to the side of the prime conductor, and afterwards melted with a candle; then if the conductor be electrified, either positively or negatively, the drop of wax becomes pointed, and shoots a number of fine threads into the air, to the distance of several feet. This thread is in the same state of electricity as the conductor it issues from.

- M It is remarkable that the drop of water which forms itself into a point by electrization does not give the spark when negatively electrified. This property is not, however, peculiar to water, but common to all very short pointed conductors that rise out of another surface nearly plane, and of some extent. A sharp metallic point rising about one thirtieth of an inch out of the surface of a ball of three inches diameter, gave sparks five or six inches in length, when positive or emitting the electric matter; but the electricity passed with-
out

out sparks, and with scarcely any noise, when the point was negative or receiving. This may be an useful criterion for distinguishing the two states.

Fig. 164, represents an instrument for distinguishing the electricities. A and B are two metallic balls, that may be placed at a greater or less distance from each other by means of the join at c. The two branches or legs c A, c B, are varnished glass. From one of the balls A, proceeds a short point towards the other ball B. If the two balls be placed in the current or course of the electric matter, so that it may pass through the air from the one to the other, its direction will be known. For if the electric matter pass from A to B, there will be a certain distance of the balls dependant on the strength of the electricity, within which dense sparks will pass from the point: but if its course be in the contrary direction, no spark will be seen, unless the balls be almost in contact, and the point will be tipped with electric light.

C H A P. IV.

OF THE ELECTRICITY PRODUCED BY BRINGING
A CONDUCTOR NEAR THE ELECTRIFIED PRIME
CONDUCTOR: AND OF CHARGING AND DIS-
CHARGING ELECTRIC PLATES.

- o If an insulated conductor, free from points, be brought within a certain distance of the prime conductor or cylinder in an electric state, it will also exhibit signs of electricity of the same kind; but if those signs be removed, by taking the spark, and the conductor taken from the prime conductor, it will exhibit signs of the contrary electricity. This is a very remarkable appearance, but may be accounted for, if two suppositions be admitted, viz. first, that the electric matter is attracted by conducting bodies; and secondly, that the parts of the electric matter mutually repel each other, the forces of each power being in a certain inverted ratio of the distance.
- p For the electric matter, in an insulated and uniform conductor, will then be equally diffused through its whole mass, and the attraction which that conductor will exert on any mass of electric matter presented from without, must be the excess of the attractive force of the body over the repulsive force of the electricity it contains. Whence a given conductor will attract the electric matter the

the most powerfully when the quantity it already possesses is the least possible, and its attractive force will decrease as it becomes more saturated with electricity. Let two equal conductors, composed of like matter, be brought within a small distance of each other, then, if the quantities of electricity they contain are equal, the attractions they mutually exert on those quantities will be equal, and it will remain undisturbed in each body. But if one conductor, A, contain more electricity than the other, B, the attractive power of B will be greatest, and will draw the electric matter from A till an equilibrium is obtained. It follows also, that in a number of conducting bodies, communicating with each other, the electric matter will be every where of the same density, if the greatest attractive force of the bodies be supposed equal; but if different bodies be supposed to attract the electric matter with different forces, as is most probable, the densities must vary with the forces. This may be called the natural state.

To apply this to the particular instance above recited, suppose the end of an insulated conductor to be brought near the prime conductor in a positive state, the attractive power of the first-mentioned conductor is greater than that of the prime conductor, yet, not being sufficient to draw sparks, at the given distance, the only effect it can produce is, to make the electric matter accumulate, and become more dense in that part of the prime conductor, near which it is presented; by which
accumulation

accumulation the rest of the prime conductor becomes less electrified, as experience testifies. This accumulated body of electricity repels, and consequently rarefies the electric matter naturally contained in that end of the conductor, which is presented to the prime conductor; the rest of the fluid becomes more dense, and the other parts of the conductor which is presented, exhibit signs of electricity; yet, as this conductor in the whole contains no more than its natural quantity, if the electric state be taken off, by drawing the spark, and it be afterwards removed from the vicinity of the prime conductor, it becomes negative throughout, by reason of the loss of the spark. If a conductor be presented to the prime conductor in a negative state, the effects are reversed, the attraction being strongest at the prime conductor, and the accumulation being in the conductor which is presented, it exhibits a negative state, which being destroyed, upon removal it becomes positive, by reason of the spark which was given to it when apparently negative.

These effects are more considerable the less the distance is between the two conductors; and the intercedent electric body is peculiarly affected: the manner of which may be better understood, by observing the phenomena of non-electrics, separated by electrics which are less liable to allow the passing of the spark than the air is.

Upon an insulated horizontal plate of metal, lay a plate of glass, considerably larger, so that there

there may be a rim of three or four inches projecting beyond the metal on every side. Upon the glass lay another plate of metal, of the same size as the former, so as precisely to cover it. Electrify the upper plate, and the lower will exhibit signs of electricity. Continue the electrization, and the lower plate will emit sparks to an uninsulated body for a time, and afterwards cease. Separate the plates from the glass without uninsulating them, and the glass will appear to be possessed of the contrary electricities on the opposite sides. That side which communicated with the prime conductor, during the electrization, will have a like electricity, and the other the contrary. Take off the electricity of the plates of metal, and carefully replace the glass on the lower, without destroying the insulation, and also replace the upper plate with the same precaution. Then, with one end of an insulated wire, not pointed, but knobbed at the ends, touch one of the plates, and bring the other end near the other plate: the consequence will be, that a strong and loud spark will pass between it and the wire, the electricity of the glass will be discharged, and the plates and the wire will exhibit few or no signs of electricity.

An electric body, whose surfaces are thus possessed of the contrary electricities, is said to be charged. The insulation of the lower metallic plate and of the discharging wire is not necessary, except for the purpose of drawing inferences, respecting

specting the manner of charging the electric plate. If the electricity of the prime conductor be strong, and the glass thick, the discharge will often be made by a spark from the one metallic plate to the other, over the surface of the glass which projects on every side; but if the glass plate be thin, in which case, at an equal intensity, it admits of a much greater charge, the discharge will be made through its substance. Glass, as thick as one eighth of an inch, may be penetrated by this means, one or more holes being made where the electric matter has passed, in which holes the glass is pulverized, and may be picked out with a pin.

w The greater the surface of the glass, the greater charge it will contain, the same intensity being supposed. But a given machine will not superinduce so strong an electric state on a large plate as a small one: the reason of which seems to depend on the different intervals of time required in the charging, conjoined with the different magnitudes of the surfaces at which the electricity is communicated to the air. If there were no escape of the electric matter during the time of charging, the times would probably be as the surfaces of the plates, equal thicknesses being always supposed; and if two plates were equally charged, the escape
x would perhaps be likewise as the surfaces. These being premised, the whole escape would be as the time of charging, and the surfaces of each conjointly, that is, because the times are as the surfaces, in the duplicate ratio of their surfaces directly.

rectly. Hence it appears that the escape in plates, that increase in size, approaches rapidly and continually nearer to the quantity of electricity supplied by the machine, and that the more powerful machine, by diminishing the time of charging, will charge higher in the inverse proportion of the time. It must be confessed that the suppositions not being accurate, the proportions are only nearly true, yet this way of considering the subject may serve to indicate the causes, though not strictly to measure the effect.

From the experiment (324), of separating the v
glass from the plates of metal, it is shewn, that
the surplus of the electricity on one surface, is
either accurately or very nearly equal to the deficiency on the other; for if it were otherwise, the plates and the discharging wire would become strongly possessed of the predominating electricity. It also follows, that if the theory of positive and z
negative electricity be true, electric bodies must contain the electric matter, for the electric states are evidently on the surfaces of the glass, independent of the metal. Now, though it may easily be understood that a positive state may be super-induced by an accumulation of electricity on one
surface, yet it is absurd to suppose that the electric matter can be emitted and exhausted from the other side, if it did not exist there, previous to such emission and exhaustion. From this circum- A
stance it may be concluded, according to the same theory, that all bodies, as well electrics as non-
electrics,

electrics, attract the electric matter, but that electrics, being so constructed as not to admit it into their substance, as non-electrics do, must condense it upon their surfaces, and at all times hold a great quantity so condensed. And if the quantity of electricity be increased or diminished on one side, the electricity on the other surface must be rarefied or condensed, in consequence of the diminution or increase of the whole attractive force of the body. The effects will also be more considerable the less the distance is between the two surfaces (321, o).

- A It is not possible to charge an electric plate by inducing an electric state on one of its surfaces, unless the other be at the same time sufficiently near to an uninsulated non-electric to assume the contrary state by emitting or receiving the electric matter.
- B If a plate of glass be laid upon an uninsulated plate of metal, the upper surface may be rendered electric by friction, or by applying an electrified body successively to its parts. This electricity may be taken off by touching the upper surface with an uninsulated metallic plate of the same dimensions as that upon which the glass is placed, but will not be entirely taken off, because the communication between the two surfaces in this method is not perfect, and because the metal cannot by ordinary means be brought into actual contact with the glass. The small quantity which remains, produces an effect which has been
- c mistaken for a perpetual electricity. For if a plate
of

of metal, to which a glass handle is affixed, be laid upon the glass, this small quantity of electricity will influence the metal, and, without actually communicating the electric matter, will cause it to exhibit a similar state (322). If this be taken off, by drawing the spark, and the metal then removed, by means of the glass handle, it will be found possessed of the contrary state of electricity, and another spark may be obtained. The metallic plate may be then again applied to the surface of the glass, and the process again repeated, and so on for a prodigious number of times, without any sensible difference in the event. For the electricity at the surface of the glass being almost in the natural state, as to condensation, does not disappear for a very long time, and the very near approach of the metal enables it to produce the same effect as would be obtained at a greater distance from a stronger electricity (321, o). This is made obvious, by bringing the metallic plate near the surface of the glass before its first strong electricity is taken off, for the same event is then perceived at the distance of four, five, or six inches, as in the former case is produced by contact.

The vapors of the atmosphere are continually attaching themselves to the surface of cold glass, and by that means destroy the electricity. Sulphur, wax, or resin, being less subject to this, retain their electric state much longer. A plate of glass or wood, coated over with any substance
of

of this nature, may be excited by friction, and will produce electricity in a metallic plate, in the manner above described for a very great length of time. Such a plate, together with its metal, has been named the electrophorus, fig. 165.

- E** If the discharge of an electrified plate be made by the parts of a living animal, a considerable pain will be felt chiefly at the extremities of the muscles. For example, if the lower metallic plate be touched with one hand, and the other brought to the upper plate, at the instant of the emission, a pain will be felt at the wrists and elbows, which as instantly vanishes. If a larger glass plate be used, the pain will be felt in the breast; if yet larger, the sensation will be that of a universal blow. This sensation has obtained the name of the shock, and will deprive animals of life, if sufficiently strong. The shock from 30 square inches of glass, well charged, will instantly kill mice, sparrows, or other small animals. Six square feet of glass will deprive a man of sensation for a time, if the head be made a part of the circuit through which the electricity moves. No inconvenience has been found from the electric shock by men of strong habits, but women of delicate constitutions
- F** have had convulsions from a violent shock. It may be observed, that the electric shock is a proof that the electric matter can pass through the substance of non-electrics, and is not universally conducted along their surfaces alone, as some have supposed.

CHẬP. V.

OF ELECTRIC JARS; THE VELOCITY OF THE
SHOCK; LIGHT IN THE BOYLEAN VACUUM;
THE CHARGING A PLATE OF AIR, WHENCE IS
DEDUCED THE ACTION OF POINTED BODIES.

FOR the sake of simplicity and precision, the effects of electricity, in charging glass, have been described as they happen in flat pieces or plate. These, however, are seldom used. The object of the philosopher, in general, is to collect a large quantity of electricity, by means of the surfaces of electrics, and it is neither necessary nor convenient to use flat plates. He therefore accommodates himself with a sufficient number of prepared jars. These are made of various shapes and magnitudes, but the most useful are thin cylindrical glass vessels, about four inches in diameter, and fourteen in height; coated within and without, with tin-foil, which is stuck on with gum-water, paste, or wax, excepting two inches of the rim or edge, which is left bare, to prevent the communication between the coatings. About four inches from the bottom, within, is a large cork, that receives a thick wire,* ending in several ramifications, which touch the inside coating; the upper end of the wire terminating with a knob, considerably above the mouth of the jar. When it is required to be charged, it may be held in the

Vol. II. Z hand,

hand, or placed on an uninsulated table, and the knob of the wire applied to the conductor; the inside coated surface becomes possessed of the electricity of the conductor, and the external surface acquires the contrary electricity, by means of its uninsulated coating. When a jar of this kind is highly charged, it will discharge spontaneously over the uncoated surface, and seldom through the glass, whereas, when the uncoated surface is large, they are more apt to break by that means, and become useless. Yet, there is no certainty that a jar, which has discharged itself over its surface, will not at another time break by a discharge through the glass, as the contrary often happens.

x A jar of considerable thickness, with a neck like a bottle, in which is cemented a thick tube to receive the wire, will sustain a very high charge, and produce much greater effects than one of the last description. The charging wire being inserted loosely into the tube, will fall out on inverting the jar, and the charge will remain for several weeks without much loss. A jar thus charged, may be put into the pocket, and applied to many purposes that the common jar cannot be used for.

When a greater degree of electric force is required, larger jars must be used, in which the form is of no consequence, except as far as relates to convenience. But it is less expensive, and nearly as effectual, to use a number of smaller jars, having the same quantity of coated surface

surface as the large jars. In this case, a communication must be formed between all the outside coatings, which may be done by placing them on a stand of metal; and also between all the inner coatings, which is best done by means of wires. Such a collection is called a battery, and may be charged and discharged like a single jar.

In discharging electrical jars, the electricity m goes in the greatest quantity through the best conductors; and by the shortest course. Thus, if a chain and a wire, communicating with the outer coating, be presented to the knob of a jar, the greater part of the charge will pass by the wire and very little by the chain, which is a worse conductor, by reason of its discontinuation at every link. When the discharge is made by the chain only, sparks are seen at every link, which is a proof that they are not in contact; and as the chain must be stretched by a considerable force before the sparks cease to appear on the discharge, it follows that there is a repulsive power in bodies, by which they are prevented from coming into contact, unless by force, as has been observed in the former part of this treatise (1. 14, A; 1. 48, A, B).

By accurate experiments it appears, that the force of the electric shock is weakened, that is, its effects are diminished, by using a conductor of great length in making the discharge. Yet, a very considerable shock was given by the Abbé Nolet, in the presence of the French King, to one

hundred and eighty men; the first of whom formed a communication with the outer coating, the rest joining hands in a circular line, and the last touched the knob of the inner coating. They were all shocked at the same instant. Dr. Watson, and many other gentlemen of eminence in the philosophical world, were at the pains of making experiments of the same kind, but much more accurate. They found, by means of wire insulated on baked wood, that the electric shock was transmitted instantaneously through the length of 12276 feet.

Q When any animal or substance is to be subjected to the shock, it is usually done by means of two chains, one of which connects one extremity of the animal or substance with the outer coating, and the other being fastened to, or laid on, the other extremity, is applied to the knob of the inner coating to make the discharge. The animal or substance thus forming a part of the circuit, R receives the whole shock. The strong shock of a battery will melt wire of the seventieth of an inch in diameter, and wires of less diameters are frequently blown away, and dispersed. Gunpowder may be fired by a charge of three square feet: the method is, to put it into a quill, and thrust a wire into each end, so as not to meet, and then make these wires a part of the circuit. A less charge will serve, if iron filings be mixed with the T gunpowder. Spirit of wine, ether, or a mixture of common and inflammable air, may also be fired
by

by the same means, or even by the spark from the conductor.

If the ball of a thermometer be placed in a strong current of electricity, the mercury or spirit will rise many degrees*.

A strong shock gives polarity to small needles. v

Electricity will pass by means of non-electrics which are so small as to be destroyed by its passage, as has just been instanced in wires: the force of the explosion in these instances is very considerable, and is termed the lateral force of electricity. The following is a proof of this, and may be exhibited with less than a square foot of coated glass, if well charged. At the glass-house there is usually x a great number of solid sticks of glass, about a quarter of an inch diameter; if these be examined narrowly, several of them will be found to be tubular for a considerable length, but the diameter of the cavity seldom exceeds the 200th part of an inch. Select these, and break off the tubular part, which may be filled with quicksilver by sucking; care being taken that no wet previously insinuates itself, and then send the shock through this small thread of quicksilver, which will instantly be dislodged, and will break or split the tube in a curious manner.

If a piece of the common glass tube be drawn y out very small, by means of the blow-pipe, and

* From 67 to 99 degrees, in a small mercurial thermometer. See Nairne's Description of his Electrical Machine. London, 1783.

then filled with mercury, the shock will cause both the mercury and the tube to disappear in the explosion; nothing being seen but smoke or vapour.

- 2 An experiment similar to these may be made with a glass-tube filled with water. Take a small glass-tube, whose cavity is about a quarter of an inch in diameter, fill it with water, and stop the end with soft pomatum: through the pomatum insert two wires, that they may almost touch each other, and make their ends a part of the circuit in the discharge of a strong shock, from about two feet square of coated glass; the consequence will be, that the water will be dispersed in every direction, and the tube blown to pieces, particularly in the middle, near the discontinuation of the wire: the ends with the wires and pomatum will sometimes be found undisturbed. This is a striking instance of the velocity and force with which the electric matter is moved (1. 40.)

A This property, of being charged and discharged, is not peculiar to glass, but is common to all other electrics.

- B If a thin bottle be exhausted of air by means of the air-pump, it will receive a considerable charge by applying its bottom to the electrified prime conductor, during which time the electric matter will pass through the vacuum between the hand and the inner surface of that part of the glass which is nearest the prime conductor. This appearance, whose cause has already been in some degree

degree explained (318), is exceedingly beautiful in the dark, especially if the bottle be of a considerable length. It exactly resembles those lights which appear in the northern sky, and are called streamers, or the aurora borealis. If one hand be applied to the part of the bottle which was applied to the conductor, while the other remains at the neck, the shock will be felt, at which instant the natural state of the inner surface is restored by a flash, which is seen pervading the vacuum between the two hands.

The electric shock may be given from a plate of air, by means of two large plates of metal, or rather boards covered with tinfoil; one of which is to be suspended to the prime conductor, and the other placed parallel to it on an uninsulated stand, at a convenient distance. These boards may be regarded as the coatings of the plate of air contained between them, and if a communication be formed between them, by touching the uninsulated board with one hand, and applying the other hand to the conductor, the shock will be felt accordingly. It is almost unnecessary to observe, that if the electricity be powerful, or the distance between the plates small, the charge will pass from the one to the other in a spark through the air.

If we compare this experiment with what has already been observed respecting the charging and discharging electric bodies, it will appear that most of the electric phenomena are the consequences

- of the air being charged. Thus, the prime conductor imparts its electricity to the surface of air immediately contiguous, and when the spark is drawn the discharge is made to the non-electrics, namely, the floor and wainscot of the room, which are in contact with the opposite surface. The charge of electrics has already been observed to be greater (323, T) the nearer the surfaces are to each other; thus, glass beyond half an inch thickness can scarcely be charged by our machines: in like manner, the discharge, that is to say, the spark from the conductor, will be greater, when a large company stand about it than at other times, the body of air which is interposed between the conductor and the nearest uninsulated non-electrics being then less in thickness than at other times.
- F It follows also, that a large conductor will give a larger spark than a less; the discharge being from a surface proportionally greater. And since this discharge consists chiefly of the electric matter, residing at, or near the surface of contact, and little, if at all, of that which may be within the substance of the conductor, it is of no consequence whether the conductor be a solid non-electric or hollow, provided the surface be unaltered in form and magnitude. Hollow cylinders of copper, or tin, or wood, or pasteboard, covered with tinfoil; or strongly gilt, are the conductors generally in use.
- H It is a consequence of the air being charged that broad non-electric surfaces draw large sparks from the

the conductor; for the sparks are the discharges of a large plate of interposed air. A less surface will draw a less spark, but because the same machine charges less surfaces higher than greater, the spontaneous discharge through the body of the electric air will be made at a greater distance of the surfaces, that is to say, the sparks will be longer. If the surface of the non-electric presented be yet less, the sparks, for the same reason, will be less, and emitted to a still greater distance. And if the surface be indefinitely small, or, in other words, if the non-electric be pointed, the spark may be so small as to be invisible, and the distance to which it can be emitted may be unlimited. The effect of pointed bodies seems to depend on circumstances of this nature; but the reason of the different appearances of the light on points electrified, positively or negatively, still remains a difficulty.

C H A P. VI.

AN ACCOUNT OF SEVERAL INSTRUMENTS, AND OF
THE PRODUCING AN ELECTRIC STATE WITHOUT
EVIDENT FRICTION.

K THE condenser is an instrument of the same kind as the electrophorus, but differently used. For instead of the interposed electric being previously charged, it is of great importance here, that it should be perfectly in the natural state. In this situation if the upper conducting plate be connected with a larger body weakly electrified, while the lower plate is uninsulated, the upper will receive the electric state, and on being separated or lifted up, will exhibit it with a much higher degree of intensity. So that very small degrees of electricity may be rendered sensible by this admirable contrivance.

L To explain the cause of this, it must be recollected that the action of a neighbouring conductor diminishes the intensity of the electric state in another conductor, more especially if the former be uninsulated. The electrified insulated conductor will therefore admit of a more considerable degree of electrization before its intensity can be rendered equal to what it was when solitary. Suppose this done, and the additional conductor then removed,
and

and it is evident that the electrified conductor will, by the uniform diffusion of the electricity, be left in a higher state of electrization than it would have acquired by the same means without the assistance of the uninsulated conductor. The two plates of the condenser are in these circumstances: the upper receives more electricity, because of the vicinity of the lower, and shews a greater intensity when removed out of that vicinity.

To accomplish this purpose, in the most effectual manner, it is necessary that the interposed electric be very thin (323, τ) and that the surfaces be well adapted to each other. The electric may be a coat of varnish laid on the lower or upper plate, or a thin silk fastened to the surface of the upper.

If the electricity be strong enough to charge the electric, the acquisition of the electric state by the metal will be counteracted on the electrophorus principle, and the charge will tend greatly to disturb and falsify the results of experiments made while it remains. A slight warming of the varnish, either by the sun or any other gentle heat, will however dissipate it. But the best remedy for this, is to use such an apparatus as will neither retain a charge nor suffer the metallic plate to obtain a higher electric state than it can carry off on its separation.

The sagacious inventor has therefore substituted, instead of the lower or fixed part of the apparatus, a piece

a piece of dry marble, or marble varnished with copal varnish and kept in an oven for a short time, or very dry wood. Here the very thin stratum of air between the metal plate and the substance it rests on, seems to supply the place of the electric, and the imperfectly conducting power of the marble or the wood, prevents any charge from being accumulated. This last apparatus also performs its office better than the other.

Q To use this instrument the metallic plate is to be laid on the marble or varnished metal, and a connection formed between the upper plate and the body whose electricity is to be examined. This connection may remain eight or ten minutes, or longer, if the electricity be very weak, and then be removed. The metal plate being lifted up, will exhibit signs of electricity if the connected body were in an electric state*.

R Various instruments have been contrived to discover the presence of electricity, together with its intensity and kind. These have been adapted to observe either the attraction, or repulsion, or the length and figure of the spark.

* The electrophorus and condenser were invented by Mr. Alexander Volta, Professor of Experimental Philosophy at Como, &c. This last instrument is honourable to its inventor, not only on account of the extensively useful purposes to which it has been and may be applied; but likewise because it was discovered, not casually, like most other electrical apparatus, but in consequence of scientific deduction and reasoning. See Phil. Transf. Vol. 72, Part 1, or Cavallo's Electricity.

Small degrees of electricity are very well shewn s by the divergence of two fine hempen-threads, suspended together from the conductor. If little r balls of pith or cork be fastened to the ends of the threads, they will serve to denote still greater intensities, as they will not so soon arrive at their utmost divergence by the mutual repulsion. Fig. v 167, is a very useful electrometer upon this principle. It consists of an upright stick of box-wood, A B, on one side of which is affixed a graduated semi-circle; D is a ball of pith or cork, and is stuck upon the end of a small rod or radius of wood, which, by means of a small axis at c, is moveable in a plane parallel to that of the semi-circle. This electrometer is fixed upright on the prime conductor; the radius will therefore hang perpendicularly down when it is not electrified; and according to the intensity of the electric state given to the conductor, the repulsion must cause the ball to ascend. The ascent will be marked by the graduations.

This electrometer, though very useful, has the v imperfection of being less sensible of the changes of electricity when the intensity is considerable, than when the repulsion at the beginning of the scale acts at right angles to the radius. It has also another inconvenience common to all electrometers, namely, the want of a standard of original adjustment, by means of which all instruments of the kind may indicate the same intensity in similar circumstances.

Fig.

w Fig. 168, represents an electrometer for measuring the length of the spark. A represents a section of the prime conductor; the wooden stem α being inserted therein.* The bent part D is varnished glass. Through a wooden collar c passes a wire that carries a ball of metal E, which may be set at different distances as required. A chain may be hung on the outer part I. This electrometer is chiefly useful for shocks, greater or less as may be required. For this purpose the knob of the jar must be in contact with the prime conductor, and a chain from F must touch the external coating. When the charge is sufficiently high, the explosion will be made through the interval between A and E.

x Fig. 169, is a very sensible electrometer, well adapted for the observation of the presence and quality of either natural or artificial electricity. ABC is the brass case containing the instrument. When the part AB is unscrewed and the electrometer taken out, it appears as represented in ABCD. A glass tube CDNM is cemented into the piece AB. The upper part of the tube is shaped tapering to a small extremity, which is entirely covered with sealing-wax. Into this tapering part a small tube of glass is cemented; the lower extremity being also covered with sealing-wax, projects a small way within the tube CDNM. Into this smaller tube a wire is cemented, which, with its under extremity, touches a flat piece of ivory H, fastened to the tube by means of a cork. The upper extremity of the,
wire

wire projects about a quarter of an inch above the tube, and screws into the brass cap *E F*, which cap is open at the bottom, and serves to defend the waxed part of the instrument from the rain, &c. From *H* are hung two fine silver wires, having very small corks at their lower ends, which by their repulsion shew the electricity. *I M* and *I N* are two slips of tin-foil stuck to the inside of the glass, and communicating with the brass bottom *A B*. They serve to convey that electricity, which, when the corks touch the glass, is communicated to it and might disturb their free motion.

To use this instrument for artificial electricity, *v* bring a body in an electric state (a stick of sealing-wax, previously rubbed, is as convenient as any) near the brass cap; the corks (*321, o*) will diverge with the same electricity till one of them touches the tinfoil *I M* or *I N*, when they will immediately collapse. Remove the electrified body, and the corks will again diverge with the contrary electricity. In this situation, supposing sealing-wax to have been used, a body possessed of the positive electricity being brought near the cap will cause the corks to diverge still more; but if negative, it will cause them to approach nearer to each other.

When this electrometer is to be used to try the *z* electricity of the fogs, air, clouds, &c. the observer is to do nothing more than to unscrew it from its case and hold it by the bottom *A B*, to present it to the air in an open place a little above his head,

so that he may conveniently see the corks *p*. A very small degree of electricity will cause them to diverge, and its quality may be ascertained by bringing an excited stick of sealing-wax, or other electric, towards the cap *EF*.

But the electrometer of Bennet, is by far the most delicate of any of the instruments which have yet been applied for distinguishing simple electricities.

It consists of two slips of leaf gold, *A*, fig. 166, suspended in a glass *B*. The foot *c* may be made of wood or metal; the cap *D* of metal. The cap is made flat on the top, that plates, books, evaporating water, or other things to be electrified, may be conveniently placed upon it. The cap is about an inch wider in diameter than the glass, and its rim about three quarters of an inch broad, which hangs parallel to the glass, to turn off the rain and keep it sufficiently insulated. Within this is another circular rim, about half as broad as the other, which is lined with silk or velvet, and fits close upon the outside of the glass; thus the cap fits well, and may be easily taken off to repair any accident happening to the leaf gold. Within this rim is a tin tube, hanging from the center of the cap, somewhat longer than the depth of the inner rim. In the tube a small peg is placed, and may be occasionally taken out. To the peg, which is made round at one end and flat at the other, the slips of leaf gold are fastened with paste, gum-water, or varnish. These slips, suspended by the peg, and that in the tube fast to the cen-

ter of the cap, hang in the middle of the glass, about three inches long, and a quarter of an inch broad. In one side of the cap there is a small hole to place wires in. It is evident, that without the glass the leaf gold would be so agitated by the least motion of the air, that it would be useless; and if the electricity should be communicated to the surface of the glass, it would interfere with the repulsion of the leaf gold, therefore two long pieces *HH* of tin foil are fastened with varnish on opposite sides of the internal surface of the glass, where the leaf gold may be expected to strike, and in connection with the foot. The upper end of the glass is covered and lined with sealing wax as low as the outermost rim, to make its insulation more perfect*.

The sensibility of this instrument is so great as even to astonish the most experienced electricians who have not before been witnesses to its effects. The brush of a feather, the projection of chalk, hair-powder, or dust, against its cap evince strong signs of electricity. The electricity of vapor is elegantly shewn by pouring a tea-spoonful of water on an agitated coal placed in a metallic cup upon the cap of this electrometer: and a very great and pleasing variety of other experiments may be made with this excellent instrument.

The ingenious electrician who is not provided with the instruments here described, may supply

* Phil. Transf. vol. 74, p. 27.

their place by contrivances which a knowledge of the general facts will easily indicate. Strong electricities may be distinguished by the light at the extremities of pointed bodies, and for less intensities a downy feather may be suspended by a fine thread of silk. This being electrified, by bringing it in contact with the cylinder or conductor of a machine, will preserve its electric state for a considerable time; during which it will be repelled by bodies in the same state, and attracted by all others:

B We shall finish this general account of artificial electricity with pointing out some of the other means of producing it, which do not seem referable to the usual method of excitation.

C The escape of vapor or elastic fluid from bodies in a state of combustion, from water thrown on hot coals, or from chemical menstrua in a state of effervescence, leaves the residue negatively electrified. These important facts seem to point at a general law of electricity, that may tend in future to explain the phenomena in which heat is latent (117, T), and to which it bears a striking analogy*.

D It appears to be a fair deduction from these facts, that as bodies take up electricity when they assume an elastic form, so they must deposit it when they are again condensed. The experiments relative to this object require to be varied and extended.

* The discovery of Sig. Volta. See Phil. Trans. vol. 72.

Sulphur melted in an earthen vessel, and placed to cool upon uninsulated conductors, is strongly electric when taken out, but is not so when it has stood to cool upon electric substances.

Sulphur melted in a glass vessel acquires a strong electricity in the circumstances above mentioned; whether the vessel be placed on electrics or not; but stronger in the former case. This electricity is yet stronger, if the glass be coated with metal. In these cases the glass is always positive, and the sulphur negative. It is particularly remarkable, that the sulphur acquires no electricity till it begins to cool and contract, and is the strongest at the time of the greatest contraction: whereas the electricity of the glass is at that time weakest, and is the strongest of all when the sulphur is shaken out before it begins to contract, or has acquired any negative electricity*.

It has been observed, that silk or worsted stockings become electrical after being worn some hours, more particularly the silk, as does also a beaver shirt worn between two others. If a white and a black silk stocking be worn on the same leg, they obtain contrary electricities. When drawn off together they shew very little signs of electricity, but, upon separating them, each indicates an electrical state so strongly, that the repulsion inflates them, so as to exhibit the entire shape of the leg. If the two stockings be allowed to come

* These facts are denied by Volta, in Phil. Transf. vol. 72.

together, they strongly attract each other, the inflation subsides, and they stick very closely together; in which situation they retain their electric state, notwithstanding the approach of the sharpest metallic point. A second separation again exhibits their respective electricities as before; and this may be done several times without much diminishing their electricities. The electricity of the black stocking is negative, and of the white positive. It is exerted by the friction of drawing the stockings from the leg.

- H The tourmalin is a hard gem, either pellucid or opaque, of a red colour, and is brought from the island of Ceylon, by the Dutch. It possesses the property of assuming an electric state if heated; one side of it becoming positive, and the other negative. If this electric state be taken off by contact, the stone will become electric as it cools; but with this difference, that the side which, during the heating, was positive, will now be negative, and the other side positive, which before was negative. But if the electric state be not taken off, the same kind of electricity will be found on the same side during the whole time of heating and cooling. Either side of the tourmalin will become positive by friction, and both may be made so at the same time.

- I These are the chief properties of this very remarkable stone, which are also common to the Brazil topaz, and some other gems. There are several important particulars relative to this and

every other branch of electrical knowledge, which cannot be enumerated and described, in an introductory book, on account of the great length of detail they would require. For these, the student must have recourse to treatises written expressly on this subject. There are also a number of fanciful and pleasing variations of the common experiments. Bells are rung by an uninsulated clapper, which is alternately attracted and repelled between two bells in opposite states of electricity; figures cut in paper are made to dance by the attraction and repulsion between two metallic plates; light mills of pasteboard are driven round by the current of air from electrified points, &c. &c. particular accounts of all which may be had in pamphlets, which are frequently sold by the makers of the electrical apparatus*.

* For a fuller account of electrical discoveries and apparatus, consult Priestley's *History of Electricity*; Adams's *Essay on Electricity*, or Cavallo's *Complete Treatise*.

C H A P. VII.

OF NATURAL ELECTRICITY; AND OF THE IDENTITY OF LIGHTNING AND THE ELECTRIC MATTER.

- K** THAT electricity is no trivial or confined subject, must appear from what has already been said, since there is no body in nature that is not acted upon by it, either as a conductor or non-conductor. The importance of the electric matter in the system of the world is more particularly confirmed by observations on those phenomena which take place without the concurrent operation of man. Of these it will be proper to give some account.
- L** Several fishes possess the property of giving the electric shock. The torpedo, or numbing fish, and one or more species of eels, from Surinam, if touched by the hand, a metal rod, or any other conductor, give a considerable shock to the arm, but may be safely touched by means of a stick of sealing-wax. The shock depends on the will of the fish, and is transmitted to a great distance, so that if persons in a ship happen to dip their fingers or feet in the sea, when the fish is swimming at the distance of fifteen feet, they are affected by it. Mr. Walfsh exhibited the actual spark of explosion by the *Gymnoblus* electricities from

from Surinam. For this purpose part of the circuit was formed of a slip of tinfoil pasted upon glass, and divided by one stroke of a sharp knife. At this break the spark was seen very luminous and bright.

Many disorders of the human frame have been cured or relieved by electricity. In all cases, except those called nervous, the electric wind from a wooden or metallic point, the spark or gentle shocks may be safely administered without fear of doing harm, if no good effect should be produced. This remedy seems peculiarly applicable to local disorders, such as swellings, contractions, rheumatic and other pains, palsies, &c. in which its effects are very often wonderfully sudden and beneficial. The spark or small shocks through the pelvis, regulated according to the feelings of the patient, are said to be an infallible cure for the suppression of the catamenia; and it is certain that in many deplorable cases it has effected a cure. It is generally admitted as a rule in the application of electricity, that it ought never to be so strong as to be disagreeable to the patient in any considerable degree.

But the most remarkable appearances of electricity, which are viewed with surprise and admiration by all ranks of people, are those which may be termed atmospherical, as for the most part existing in, or depending on, the state of the atmosphere. Lightning is proved to be an electric phenomenon, and there is little doubt but the au-

rora-borealis, whirlwinds, water-spouts, and earthquakes, depend on the same principle.

- o The resemblance between the electric spark and lightning, is so obvious, that we find it among the earliest observations on the subject; but the proof of the important theorem of their identity was reserved for Dr. Franklin, who is so justly celebrated for his many discoveries in this branch of natural philosophy. He first observed the power of uninsulated points, in drawing off the electricity from bodies at great distances, and thence inferred that a pointed metallic bar, if insulated at a considerable height in the air, would become electrical by communication from the clouds during a thunder-storm. He communicated this thought to the public; and several machines, consisting of insulated iron bars, erected perpendicular to the horizon, and pointed at top, were set
- p up in different parts of France and England. The first apparatus that was favored with a visit from this ethereal matter, was that of Mons. Dalibard, at Marly la Ville, about six leagues from Paris. It consisted of a bar of the length of forty feet, and was electrified on the tenth of May, 1752, for the space of half an hour, during which time the longest sparks it emitted measured about two inches.

- q Dr. Franklin, after having published the method of verifying his hypothesis concerning the sameness of electricity with the matter of lightning, was waiting for the erection of a spire in Philadelphia

Philadelphia to carry his views into execution; not imagining that a pointed rod of a moderate height could answer the purpose; when it occurred to him, that by means of a common kite he could have a readier and better access to the regions of thunder, than by any spire whatever. Preparing therefore a large silk handkerchief, and two cross sticks of a proper length, on which to extend it; he took the opportunity of the first approaching thunder-storm, to walk into a field in which there was a shed convenient for his purpose. But, dreading the ridicule which too commonly attends unsuccessful attempts in science, he communicated his intended experiment to nobody but his son, who assisted him in raising the kite.

The kite being raised, the end of the string being tied to a silk string, which he held in his hand, and a small key being fastened at the place of junction, a considerable time elapsed before there was any appearance of its being electrified. One very promising cloud had passed over it without any effect; when, at length, just as he was beginning to despair of his contrivance, he observed some loose threads of the hempen string to stand erect, and to avoid one another just as if they had been suspended on a common conductor. Struck with this promising appearance, he immediately presented his knuckle to the key, and, let the reader judge of the exquisite pleasure he felt at the moment, the discovery was complete. He perceived a very evident electric spark. Others succeeded,

succeeded, even before the string was wet, so as to put the matter past all dispute; and when the rain had wetted the string, he collected the electricity very copiously. This happened in June 1752, a month after the electricians in France had verified the same theory, but before he had heard of any thing they had done.

s ' The grand practical use which the Doctor made of this discovery, was to secure buildings from being damaged by lightning, a thing of vast consequence in all parts of the world, but more especially in several parts of North America, where thunder-storms are more frequent, and their effects, in that dry air, more dreadful, than they are ever known to be with us.

T This great end is accomplished by so easy a method, and by so cheap and seemingly trifling apparatus, as fixing a pointed metalline rod higher than any part of the building, and communicating with the ground, or rather the nearest water. This wire the lightning is sure to seize upon, preferably to any other part of the building, unless it be very large and extended, in which case wires may be erected at each extremity; by which means this dangerous power is safely conducted to the earth, and dissipated without doing any harm to the building.

U Conducting rods are now become very common, both for the purpose of securing buildings, and of making observations on the state of the atmosphere. The best of those which are intended
for

for the latter purpose, is the following. On the top of any building, which will be the more convenient if it stand upon an eminence, erect a pole as tall as a man can manage without difficulty, having on the top of it a solid piece of glass or baked-wood, a foot in length. Let this be covered with a tin or copper vessel in the form of a funnel, to prevent its ever being wetted. Above this let there rise a long slender rod, terminating in a pointed wire, and having a small wire twisted round its whole length, to conduct the electricity the better to the funnel. From the funnel, let a wire descend along the building, about a foot distance from it, and be conducted through an open sash into any room which shall be most convenient for managing the experiments. In this room let a proper conductor be insulated and connected with the wire coming in at the window. This wire and conductor, being completely insulated, will be electrified whenever there is a considerable quantity of electricity in the air; and notice will be given when it is properly charged, either by the mutual repulsion of two small balls of cork hung to it by threads, or by the ringing of two small bells, the one suspended from, and communicating with the conductor, and the other uninsulated: these bells will be in opposite states of electricity when the conductor is electrified, and if a clapper or small metallic ball be hung by a silk thread between them, it will be alternately attracted and repelled by each, and consequently

quently indicate the electricity of the conductor w by ringing. The condenser (339, κ) is of excellent use to ascertain the presence and quality of atmospheric electricity when the conductor is too slightly electrified to attract a thread, or to exhibit any of the usual appearances.

- x To make these experiments in perfect safety, the electrified wire should be brought within a few inches of a conducting rod, which serves to guard the house, that the redundant electricity may pass off that way, without striking any person who may happen to stand near it. The conductor to guard the house should consist of a rod, without breaks or discontinuities, between one fourth and one half of an inch thick, if it be of iron, but smaller if it be of brass or copper, terminating upwards in a sharp point about four or five feet above the highest part of the building: it is convenient that this point be of gold, or gilt, to preserve it from rusting. The lower end of the rod should, if possible, be continued to some well or running water, or otherwise it should be sunk several feet into the ground, at the distance of some yards from the building. It is of no consequence how many bendings are made in the rod, but it is much better to fasten it to the outside than the inside of the building; for these conductors are known to emit sparks during thunder-storms, notwithstanding their insertion in the earth, from which fatal consequences may be apprehended when the electric force is very great.

It is clear, from many instances, that the lights which are seen at the mast-heads of ships, and on the vanes of some churches during thunder, owe their origin to the electric matter passing by means of uninsulated points.

The polarity of the compass-needles has been known, in several instances, to have been destroyed or reversed by lightning. An effect which, as has been observed, may be produced by the electric shock from glass (334, v).

If the electrician be desirous of making experiments upon the electricity of the atmosphere to greater exactness, he must raise a kite, by means of a string in which a small wire is twisted. The lower extremity of this line must be silk, and the wire must terminate in some metallic conductor of such a form as shall be thought most convenient. But it is dangerous to raise it upon the approach of a thunder-storm; and upon this occasion the common apparatus for drawing electricity from the clouds will probably answer every intended purpose.

C H A P. VIII.

OF LIGHTNING, AND OTHER METEORS.

B To know that lightning and the electric matter are the same, is a great step in natural philosophy, but we must still remain ignorant of the causes of many of the appearances which accompany lightning, so long as our acquaintance with the properties of electricity is so very imperfect. We
e know that the clouds are almost always electrified, sometimes positively, and sometimes negatively; but whence, or by what means, they acquire that
D state; whether by the heating or cooling of the air, upon the Tourmalin principle, whatever that may
x be, or whether the clouds be only the conductors by which the electric matter is conveyed through the air, from places in the earth where it is redundant, to other places where there is a deficiency, cannot easily be determined. The first is the conjecture of the well-known Mr. Canton, and the latter is the chief proposition in the theory of that great philosopher Sig. Beccaria of Turin. It is probable that both circumstances may conduce to the effect; the heating or cooling of the air may produce, or rather collect, that electricity, which is so great an agent in atmospheric events, and its discharge may be effected in the
manner

manner in which Signor Beccaria has, with great probability, supposed it to be accomplished.

The discovery of Sig. Volta, of the electricity of vapors, or elastic matter raised into the atmosphere by fire or otherwise, is a most capital advance towards the perfect knowledge of the cause of the electric state of clouds, mists, and the like. For vapors, carrying off a larger portion of electricity than when in the fluid state, must constantly give out a part of the same (346, D) when they arrive in the superior and colder regions of the air, where they become more condensed, and form clouds. Clouds and rain will therefore naturally have the positive electricity, though a cloud, when once formed, may, by its influence on neighbouring clouds, cause them to become negative (321, O), by imparting not only their natural surplus, but even more to the earth.

A thunder-storm usually happens in calm weather. A dark cloud is observed to attract others to it, by which it continually increases in magnitude and apparent density. When the cloud is thus grown to a great size, its lower surface swells in particular parts towards the earth, sometimes by light flimsy clouds, and sometimes by an inferior protuberance. During the time that the cloud is thus forming, flashes of lightning are seen to dart from one part of it to the other, and often to illuminate the whole mass; and small clouds are observed

observed moving rapidly, and in very uncertain directions beneath it. When the cloud has acquired a sufficient extent, the lightning strikes the earth in two opposite places; the path of the lightning lying through the whole body of the cloud and its branches.

- H That thunder-clouds frequently do nothing more than conduct the electric matter from one place to another, is not only probable, on account of its striking in two places, but likewise from the consideration, that the emission of the flash would destroy the electric state of the clouds, if it were not immediately recruited from some other part. But the electric state is not destroyed after a flash, if we may judge either from the electric apparatus, or from the cloud itself; ~~for~~ the first appears to be not less electrified, and the latter is the next moment ready to make as great a discharge as before. Besides, if the two flashes of lightning, which strike at different places, nearly at the same time, were simple, similar, and independent discharges of the cloud, why should they resemble each other? and yet they do very much, as appears by observing a thunder-storm at a distance. Then it is seen, that if one part of the cloud give a single flash, the other extremity will give, or rather receive, a single flash a short time or the instant after; but if it give two, three, or four quick successive flashes, the other extremity will receive a like number a little, but very perceptible a time after. The angular distance between

tween the places of these correspondent flashes is frequently four or five points of the compass.

It is remarkable, that most detached clouds, whose angular heights are but small, and which consequently may be viewed in profile, are variously arched at their upper surface, while their under surface is horizontal. This appearance is particularly observable in thunder-clouds, and also takes place in the smoke of resin, or steam of water, electrified by the common machine.

Whatever may be the cause that disturbs the equilibrium of the electric matter in the atmosphere, it may easily be conceived, that when such disturbance happens in the upper, and highly rarefied regions of the air, the equilibrium will be restored by dartings and electric coruscations through the vacuum, similar to those exhibited in the vacuum of the air-pump. This consideration accounts for the aurora borealis, which has commonly a motion of darting or undulating between two opposite parts of the heavens.

In clear and calm weather, when the electricity is not very strong, it may pass through the air without bringing any great quantity of vapours into its course, and, according to the conductors it meets in the air, it will sometimes be rendered visible for small parts of its passage, and occasion those appearances which we call shooting-stars. It is observable, that shooting-stars, seen at any time, in general all direct their course the same way.

M The balls of * fire, as well as the shooting-stars, occasionally seen in the air, seem to be masses of electricity, at so great a distance that their angular velocity is not sufficient to prevent the eye from discerning their shape. It is probable that every electric spark or flash of lightning consists of one or more balls of fire, though their extreme velocity presents them to the eye under the form of a line or lines (1. 259, 0).

N The ignis fatuus, or Will-with-the-wisp, is a luminous meteor that seldom appears more than six feet above the ground. It is found chiefly about bogs, and is always in motion, varying both its figure and situation in a very uncertain manner. In the plains in the territory of Bologna, they are frequently very large, and give a light equal to a torch; and there are some places where one may be almost sure of seeing them every dark night. It has been conjectured that these meteors consist of inflammable air, which has been kindled by electricity.

O It was observed of water-spouts, that the convergence of winds and their consequent whirling motion, was a principal cause in producing that effect (63, 1); but there are appearances which can hardly be solved by supposing that to be the only cause. They often vanish, and presently appear again in the same place: whitish or yellowish

* Dr. Blagden has given a valuable statement of facts and deductions respecting meteors of this kind in the Phil. Trans. vol. 74.

flames have sometimes been seen moving with prodigious swiftness about them, and whirlwinds are observed to electrify the apparatus very strongly. The time of their appearance is generally those months which are peculiarly subject to thunder-storms, and they are commonly preceded, accompanied, or followed by lightning; the previous state of the air being alike in both cases. And the long established custom, which the sailors have, of presenting sharp swords to disperse them, is no inconsiderable circumstance in favour of the supposition of their being electrical phenomena. Perhaps the ascending motion of the air, by which the whirling is produced, may be the current known to issue from electrified points, as the form of the protuberance in the sea is somewhat pointed; and the electrified drop of water, heretofore mentioned, may afford considerable light in explaining this appearance.

It is extremely probable that earthquakes owe their original to the discharge between a cloud and the earth, in a highly electric state, or even between two clouds. They happen most frequently in dry and hot countries, which are most subject to lightning and other electrical phenomena; and are even foretold by the electric convulsions and other appearances in the air, for some days preceding the event. Earthquakes are attended by no fire, vapor, or smell, which however could hardly fail to appear, if the common opinion, of their being occasioned by a subterra-

neous explosion, were true. The effect of an explosion of this nature would be a gradual lifting of the earth, after which it would fall again, and, no doubt, destroy or change the course of springs, and considerably alter the face of the country: the contrary to all which is true; for, as far as observation can determine, the shock of an earthquake is instantaneous to the greatest distances, and seldom does more mischief than overthrowing buildings. Earthquakes are usually accompanied by rain, and sometimes by the most dreadful thunder-storms. All these, and many more circumstances, but especially the almost instantaneous motion of the shock, induce us to look for their cause in electricity, the only power in nature that acknowledges no sensible transition of time in its operations.

Q Dr. Priestley, in his History of Electricity, has given an abridgment of Dr. Stukely's observations and inferences on this subject, and has himself shewn, by experiment, that the electric shock causes a vibration similar to that of an earthquake, when it passes at or near the surfaces of bodies.

R It may be here observed, that the knowledge we have of the properties of electricity has been acquired, for the greater part, within the last half century; and that if discoveries proceed as rapidly as they have began, it may be hoped, that a similar period will afford a more perfect acquaintance

acquaintance with the influence of electricity not only on atmospherical events, but likewise on magnetism, vegetation, muscular motion, and other appearances, in which, it is more than probable, this great and active power has a share.

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